Model 5012

Instruction Manual

Multi Angle Absorption Photometer (MAAP)
Software V1.32/1.33
Part Number 100076-00
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CE

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CHAPTER 1
INTRODUCTION

The Model 5012 Multi Angle Absorption Photometer (MAAP) black carbon monitor measures ambient and source black carbon (BC) concentrations and aerosol light absorption properties. The Model 5012 combines proven detection technology, easy to use menu-driven software, and advanced diagnostics to offer unsurpassed flexibility and reliability. The Model 5012 has the following features:

- Multi-line alphanumeric display
- Menu-driven software
- Field programmable sample averaging times
- Multiple analog outputs
- High sensitivity
- Excellent linear response
- Mitigation of aerosol scattering interferences
- Long-life optics and detectors
- Automatic temperature and pressure correction
- Internal quality assurance and data storage features

Thermo Fisher Scientific is pleased to supply this continuous BC monitor. We are committed to the manufacture of instruments exhibiting high standards of quality, performance, and workmanship. Thermo service personnel are available for assistance with any questions or problems that may arise in the use of this analyzer.

PRINCIPLE OF OPERATION

The Model 5012 is based on the principle of aerosol-related light absorption and the corresponding atmospheric black carbon (BC) mass concentration. The Model 5012 uses a multi angle absorption photometer to analyze the modification of radiation fields in the forward and back hemisphere of a glass-fiber filter caused by deposited particles. The data inversion algorithm is based on a radiation transfer method and therefore takes multiple scattering processes inside the deposited aerosol and between the aerosol layer and the filter matrix explicitly into account.

The sample is drawn into the Model 5012 through the inlet, as shown in Figure 1-1. The sample flows through the downtube and deposits onto the glass fiber filter tape. The filter tape will accumulate an aerosol sample towards a threshold value, whereupon the filter tape will automatically advance prior to reaching saturation. Within the detection chamber a 670-nanometer visible light source is aimed towards the deposited aerosol and filter tape matrix. The light transmitted into the forward hemisphere and reflected into the back hemisphere is measured by a series of photo-detectors. During sample accumulation the light beam is attenuated from an initial reference reading from a clean filter spot. The reduction of light transmission, multiple reflection intensities, and air sample volume are continuously integrated over the sample run period to provide a real-time data output of black carbon concentration measurements.

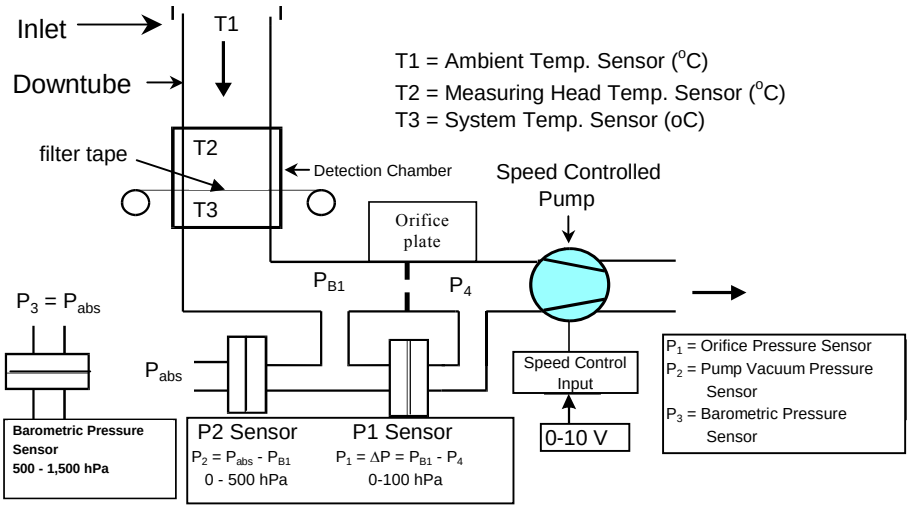


Figure 1-1. Model 5012 MAAP Flow Schematic

The Model 5012 black carbon (BC) measurement is the end-result of optically absorbed aerosol that are primarily derived from carbonaceous particulate emissions from combustion sources. Post-collected data may be converted to the aerosol light absorption coefficient by applying the specific attenuation factor (sigma) used in the Calibration menu.

The design of the Model 5012 is ground breaking in that it captures the physics of the radiative transfer of aerosol by isolating and removing scattering effects that can interfere with optical absorption methods. In Figure 1-2 the detection chamber schematic is presented.

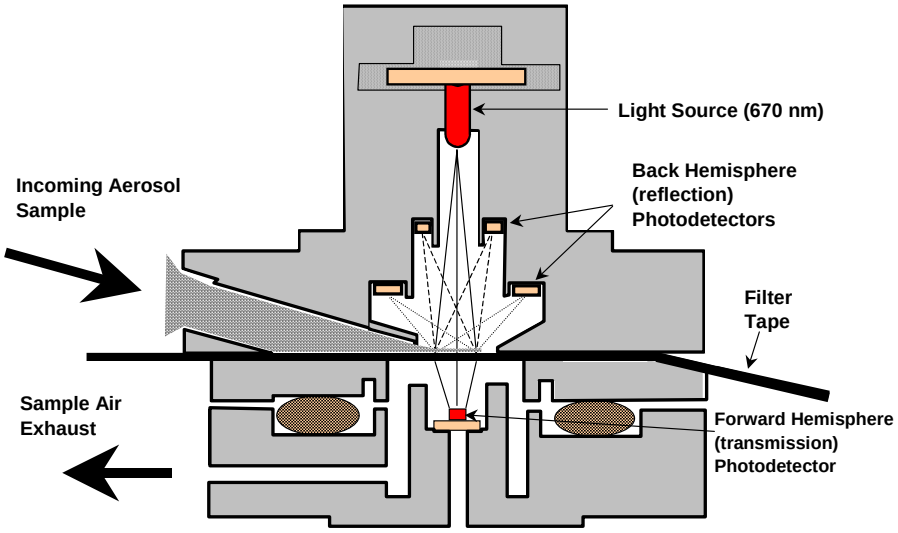


Figure 1-2. Model 5012 MAAP Detection Chamber

The Model 5012 outputs the BC concentration to the front panel display, the analog outputs, and serial outputs.

SPECIFICATIONS

BC Measurement Range:	0-60, 0-180, µg/m³ BC @ 30, 10, averaging, respectively. (95 % confidence level, 1000 l/h)
Lower Detection Limits: (95 % confidence level, 1000 l/h)	10 min value: < 50 ng/m³ BC; < 0.33 Mm^{-1} B*abs* 30 min value: < 20 ng/m³ BC; < 0.13 Mm^{-1} B*abs*
Temperature Measurement:	–30 to +70°C; Linearity error < 1%
Pressure Measurement:	P1: 0-100 hPa; P2: 0-500 hPa; P3: 500-1500 hPa (absolute); Linearity error < 1%
Sample Flow Rate Measurement:	0.5-1.4 m^3/h; Linearity error < 1% @ 16.7 L/min
Ambient Operating Conditions:	–20 to +50°C ; 20 – 80% RH non condensing 750 - 1050 hPa Barometric Pressure
Physical Dimensions:	19.0" (W) X 12.4" (H) X 12.6-15.75" (D)
Total Weight:	55 lbs (25 kg)
Power Supply:	110 V / 220 V; Central unit 30 W; Pump approx. 100 W
Filter Tape:	Glass fiber filter GF 10; Length approx. 40 m Retention degree 99.98 %
Data Storage:	385 days
Display:	LCD – module with 4 x 20 characters and 3 LEDs
Keyboard:	4 keys
Electronics:	Z80 processor 64 Kbytes Flash-memory 8 Kbytes CMOS-RAM Battery buffer for CMOS-RAM Connection for LCD-display with keys and LEDs Seiko hardware clock

Analog Output:	2 analog outputs 12 Bit, each with two ground related power sources 0-20 mA (0-10 V) for mass and concentration (separate power sources for front plug and back plug) 1 analog output 0-10 V, 12 Bit for air flow regulation
Thyristor for Pump:	Switched d.c. outputs 15 V for - d.c. motors - status relays
Status Relays:	3 status relays with protective wiring 1) Switch input for filter change initialization via external contact 2) Interface for extension boards 3) Interface for filter tape printer
Analog I/O Extension:	Four additional analog outputs with power sources
BIT I/O Extension:	Six relays with protective wiring and four opto-decoupled inputs

Potential Separation for 20 mA Analog Interfaces

Measured Value Outputs:	Analog outputs for mass and concentration of black carbon

Linear Output, Output Range Freely Selectable:

Voltage output:	0..10 V, load > 2 kΩ
Current output:	0..20 mA, 4..20 mA, load: 0..500 Ω

Potential Separation with Plug-In Module for Each Output Separately

Serial interface:	-V24/RS232 (printer or PC connection) 300..9600 Bd
Storage Capacity:	18,560 CBC entries Log-book with 1,632 entries Daily mean values (385 days)
Contacts for In- and Outputs:	1 control input 3 alarm- and status signals via potential-free relay contacts Rating of the contacts: 0.5 A/60 V

CHAPTER 2
INSTALLATION

The installation of the Model 5012 includes lifting the instrument, unpacking the instrument, connecting sample and vacuum lines to the instrument, attaching the analog outputs to a recording device, and setting up any serial communications. For more information about optional equipment (e.g., inlet assemblies, expansion boards), see Chapter 9, "Optional Equipment."

LIFTING

A procedure appropriate to lifting a heavy object should be used when lifting the monitor. This procedure consists of bending at the knees while keeping your back straight and upright. The monitor should be grasped at the bottom, in the front and at the rear of the unit. Do not attempt to lift the monitor by the cover or other external fittings. While one person may lift the unit, it is desirable to have two persons lifting, one by grasping the bottom in the front and the other by grasping the bottom in the rear.

UNPACKING

The Model 5012 central unit is shipped in one container and the pump and any inlet assemblies are shipped separately. If, upon receipt of the monitor, there is obvious damage to the shipping container, notify the carrier immediately and hold for inspection. The carrier, and not Thermo Electron Corporation, is responsible for any damage incurred during shipment. Follow the procedure below to unpack and inspect the instrument.

1. Remove the instrument from the shipping container and set on a table or bench that allows easy access to both the front and rear of the instrument.
2. Remove the instrument cover to expose the internal components.
3. Remove any packing material.
4. Check for possible damage during shipment.
5. Check that all connectors and printed circuit boards are firmly attached.
6. Re-install the instrument cover.

SETUP PROCEDURE

1. Connect the sample line to the sample connector on the top panel (see Figure 2-1). Ensure the upstream sample line (size selective inlet assembly and downtube or sampling cane) is not contaminated by dirty, wet or incompatible materials. For a size-selective inlet assembly, refer to Chapter 9, "Optional Equipment." If using a standard sampling cane inlet, all tubing should be constructed of Tygon® R-3603

vacuum tubing with an OD of 1-3/8" and a minimum ID of 5/8" and a compatible hose clamp. The Tygon tubing must be connected to the rigid sample cane connector prior to the instrument. The length of Tygon tubing should be minimized to prevent significant sample loss of particles >0.5 micrometer and the last 3 feet (1 m) of transparent sample tubing should be optically shielded to prevent any light leakage into the detection chamber. If the sample line runs more than 30 feet (10 m) it is suggested that rigid tubing be used. If statically charged particles are to be sampled, static-dissipating tubing should be used.

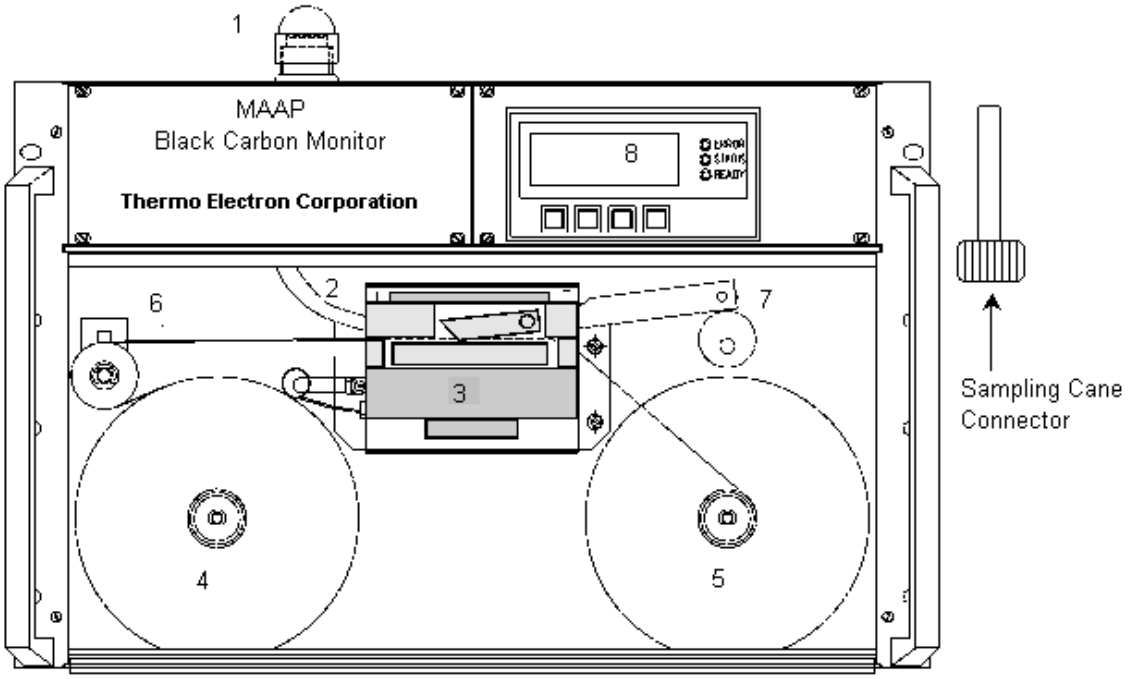


Figure 2-1. Model 5012 Front Panel and Tubing Connector

(1) Sample connector
(2) Air supply to the detection chamber
(3) Lower detection chamber
(4) Filter tape supply reel
(5) Filter tape take-up reel
(6) Reversing roller and filter tape transport sensor
(7) Chamber cam
(8) Display
(9) Standard 25-pin female I/O connector

NOTE: All aerosol must be delivered to the instrument at atmospheric pressure. It may be necessary to employ an atmospheric bypass plumbing arrangement, as shown in Figure 2-3.

2. Connect the pump vacuum line to the vacuum connector on the rear panel (see Figure 2-2).
3. Connect the pump exhaust to a suitable vent or filter.
4. Connect the 9-pin pump voltage control connector to the rear panel (see Figure 2-2).
5. Connect the central unit power cord to the rear panel of the instrument.
6. Plug the instrument into a designated wall outlet of the appropriate voltage and frequency.
7. Plug the pump power cord into the rear of the instrument.

CAUTION: The Model 5012 central unit and pump are supplied with three-wire grounding cords. Under no circumstances should this grounding system be compromised.

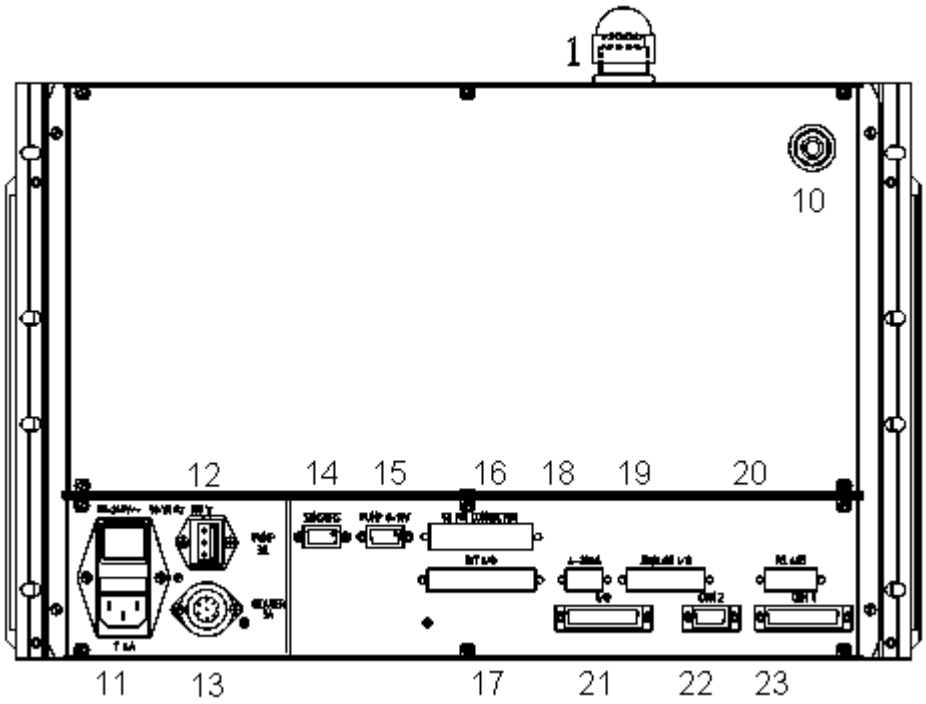


Figure 2-2. Model 5012 Rear Panel

(10) Vacuum pump tube connection
(11) Power connection, fuse, and main switch
(12) Pump power connection
(13) Optional heater connection
(14) Temperature sensor connector
(15) Pump voltage connector
(16) 50-pin network connector (option)
(17) Female I/O extension (option)
(18) Additional analog outputs 4-20 mA (option)
(19) Extension of the analog I/O by 8 in and 4 out (option)

(20) Not used
(21) 25-pin I/O connector
(22) COM2 serial data interface V.24/RS 232, 9-pin D-sub female connector
(23) COM1 serial data interface V.24/RS 232, 25-pin D-sub female connector

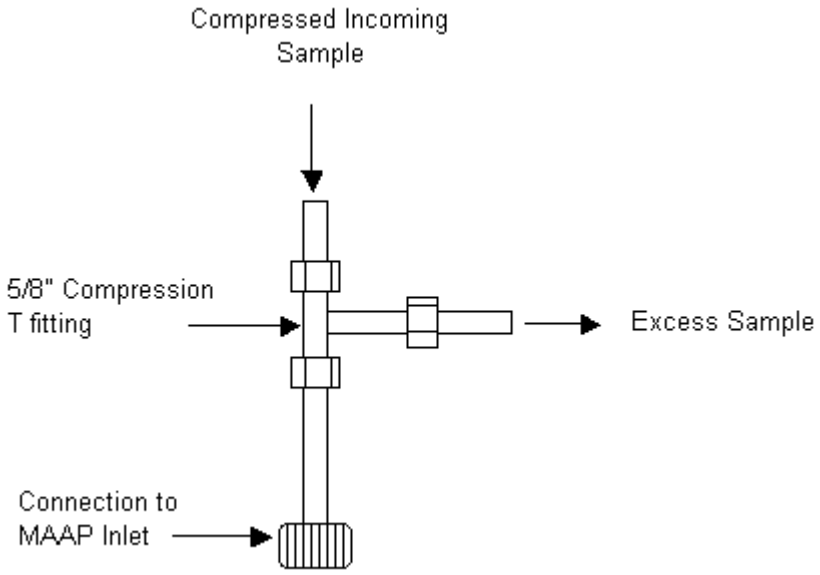


Figure 2-3. Atmospheric Dump Bypass Plumbing for Source Measurement

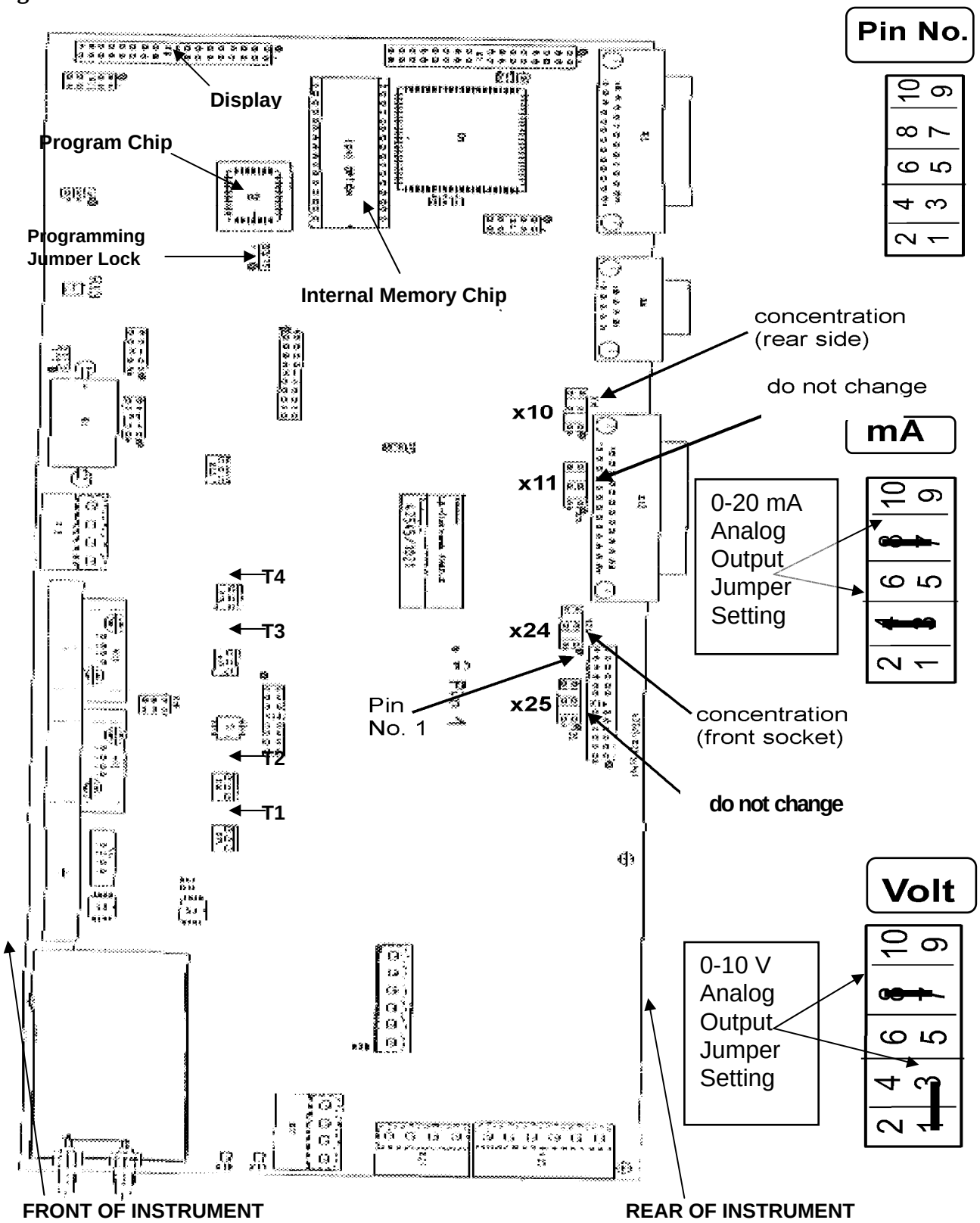
ANALOG OUTPUT INSTALLATION

Unless specified upon order, the Model 5012 comes equipped with a default analog output signal of 0-20 milliamps (mA). In order to configure the Model 5012 for an analog output of 0-10 volts (V), jumpers on the main circuit board must be repositioned. If the output signal jumpers are to be changed, **TURN THE POWER TO THE INSTRUMENT OFF FIRST AND UNPLUG FROM THE POWER SUPPLY!**

The Model 5012 analog output of black carbon concentration can be accessed from either the front or rear I/O socket on the central unit. Pin numbers 12 and 13 from the I/O socket are used as the (+) 0-20mA/0-10V concentration signal and as the
(-) 20mA/ground connectors, respectively.

In order to switch the analog output signal from mA to V, the jumper settings on the circuit board must be changed. Please reference Figure 2-4 to make any necessary changes. In this figure, locate the four (4) connectors labeled x10, x11, x24, and x25 towards the right side of the circuit board. These connectors run from top to bottom in Figure 2-4 and are towards the rear of the instrument. Each connector comes from the factory with the jumpers connected to pins 3-4 and 7-8, and this provides an analog output of 0-20 mA.

Figure 2-4. Model 5012 Main Circuit Board



For a description of the connector pin layout, see the upper right hand corner of Figure 2-4 labeled:

Pin No.

To complete a change of jumpers, access the circuit board by unscrewing the six (6) small screws on the small access panel on the lower rear of the instrument (Be sure to disconnect the power supply before accessing the circuit board). Gently pull the panel with fixed circuit board outward only 2 inches (5 cm) to expose the connectors.

To configure the analog output for **VOLTAGE**, change the jumper settings on connector x10 and x24 only (as referenced in Figure 2-4) to provide a 1-3 and 7-8 jumper setting per connector. **Do not** change the jumper settings on connectors x11 and x25. Gently insert the circuit board and secure the rear access panel with the six (6) screws. Power on the central unit and check for voltage output readings.

Note: Although the jumpers have now been changed for a voltage output signal, the Display Menu will still show mA as the analog output. Please apply 0 mA = 0 V; 4 mA = 2 V and 20 mA = 10 V.

To revert back to an analog output in mA, follow the above instructions and place the x10 and x24 connectors into the original jumper settings of 3-4 and 7-8.

Any information regarding Serial Data Output is discussed in Chapter 3, “Operation,” and RS-232 Commands are provided in Appendix B, “Commands.”

STARTUP

1. Turn the power on.
2. Set instrument parameters such as automatic filter change frequency and hour, flow rate, analog output scaling, language, and averaging time. For more information about the instrument parameters, see Chapter 3, “Operation and Service.”
3. Before beginning actual monitoring, perform a calibration of all temperature sensors and the barometric pressure sensor, followed by flow rate. For more information about calibrating the Model 5012, see Chapter 4, “Calibration.”

FILTER TAPE INSTALLATION

1. Using the Maintenance Menu, enable the keypad and Open the Detector Head (see Chapter 3, “Operation”).
2. Open the front transparent cover plate of the instrument’s central unit.
3. Loosen the knurled nuts on both the supply reel (4) and the take-up reel (5) and remove any used filter tape and empty the supply spool.
4. Put a full roll of tape on the filter tape supply reel (4), and place the empty take-up spool on the filter tape take-up reel (5).
5. Feed the filter tape from the supply reel clockwise around the reversing roller (6), through the left side of the detection chamber, and fix the filter tape to the filter tape take-up reel (5) using double-sided sticky tape.
6. Hand-tighten the knurled nuts on both the supply reel (4) and the take-up reel (5).
7. Using the Maintenance Menu, enable the keypad and advance the filter tape until it has wrapped around itself twice on the take-up reel (5).
8. Using the Maintenance Menu, enable the keypad and Close the Detector Head.
9. Press the **BACK** key until the display is back to the Main Menu and initialize a filter change cycle by pressing the **FC+Z** key.
10. Replace the front transparent cover plate on the central unit.

In case the inserted filter tape is not correctly tensioned (i.e., in case the reversing roller does not turn during the filter change cycle), the pump will be switched on immediately after the filter tape change is complete, but at the same time a corresponding error status will be set. Consequently, the filter tape needs to be checked. After investigation, another filter change cycle has to be initialized by pressing the key **FC+Z** again.

CHAPTER 3
OPERATION AND SERVICE

This chapter describes the front panel display, keypad pushbuttons, and menu-driven software for the Operation and Service menus. The Calibration Menu will be covered in Chapter 4.

DISPLAY

The 4 line by 20 character alphanumeric display shows the sample concentration, instrument parameters, instrument controls, and help messages. Some menus contain more items than can be displayed at one time. For these menus, use the **BACK** and **NEXT** pushbuttons to move through the menus and submenus.

KEYPAD

The keypad of the Model 5012 consists of 4 keys to operate the instrument. Together with the display unit, these keys form the interactive user surface. The functions that are covered by the single keys are described in the lowest line of the display.

BACK,NEXT	Moving backwards and forwards within the menu
YES	Entering a sub-menu, Carrying out the action(s) being displayed
YES,NO	Switching on/off parameter flags
+, –	Setting numerical values

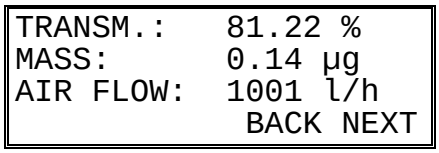
These keys are only for general information. The additional key functions that are more individual or specific are described in the corresponding menu descriptions.

During normal operation, the keyboard usually is locked. The majority of the menu points and all displays can be accessed by pressing the **BACK, NEXT** and **YES** keys. Changing operational and calibration parameters are only possible after enabling the keyboard. With the keyboard enabled only operational changes are possible. To calibrate the unit, a code must be entered to access calibration rights.

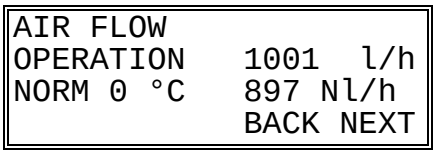
MAIN MENU

STATUS:0000 NORMAL ERROR: 00 CBC: 780ng/m3 DISP BACK NEXT	STATUS:0001 CHANGE ERROR: 00 CBC: 780ng/m3 DISP BACK NEXT	STATUS:0002 ZERO ERROR: 00 CBC: 780ng/m3 DISP BACK NEXT

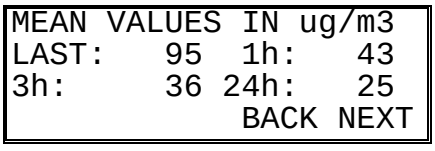
In the Main Menu display information is found on the status and the concentration of black carbon (CBC). The concentration value in nanograms per cubic meter (ng/m^3) will be updated each time interval. By pressing **DISP** and **NEXT** other values such as percent light transmission, mass of black carbon, air flow rate, average concentration values, error status, and time can be displayed. The Main submenus are as follows:



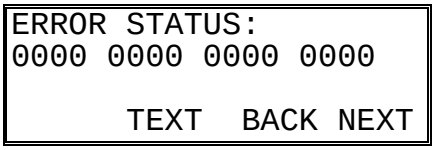
Displays light transmission and the two most important basic values: mass of black carbon in micrograms and air flow rate in liters per hour.



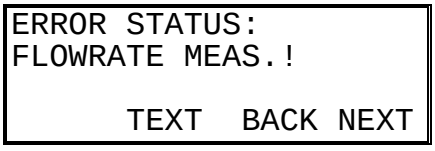
This display shows the volumetric flow at the sampling inlet and the air flow rate referenced to STP conditions (standard temperature and pressure, 0°C & 1013 hPa). Please note the standard temperature is adjustable.



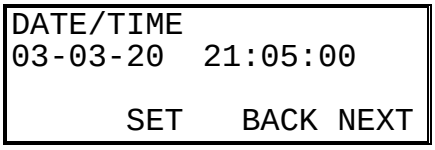
This display gives an overview of the mean CBC of the last measured value (LAST), of the last hour (1h), of the last three hours (3h), and of the previous day (24h). The 24h mean value is only refreshed once a day at midnight. The other values are continuously updated.



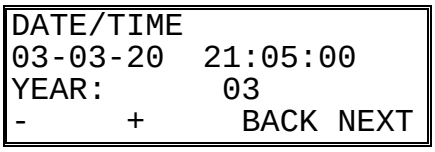
Here, the error status is shown. Each character represents four error bits, assuming values in the range of 1 and F (hexadecimal: 16). To interpret the error status, see Chapter 6, "Troubleshooting".



This display provides the device error as plain text, but only with rough details. In case of more than 2 device errors, the remaining errors can be seen by pressing the **TEXT** key repeatedly.

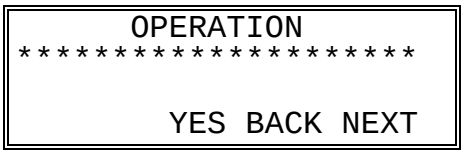


The date and time display has the format:
year-month-day hour:minute:second
By means of the **SET** key, adjustment of the current date and time is possible, starting with the year down to the seconds (keyboard must be enabled).

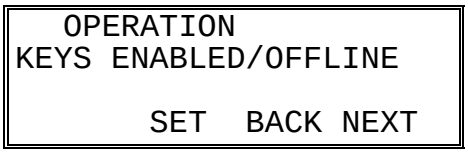


To set the respective value, press the **+, -** keys.

OPERATION MENU

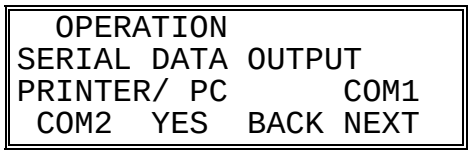


Press:
YES: to enter the Operation Menu
BACK: to return to the Main Menu
NEXT: to enter the Service Menu

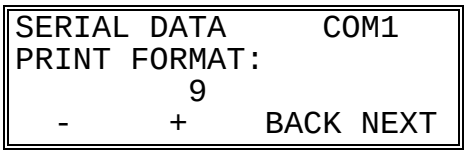


To toggle between the operation via keypad and serial interface, press the **SET** key. Please remember that parameters cannot be set nor actions released without having enabled the keypad.

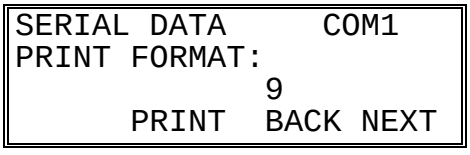
Serial Data Output



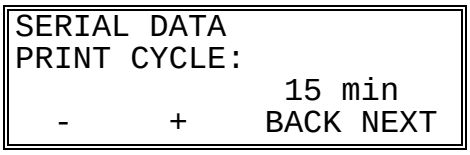
Pressing the **COM1/COM2** keys toggles between the COM1 and COM2 interface. Apart from the print cycle and the device address, all interface parameters for COM1 and COM2 can be set individually.



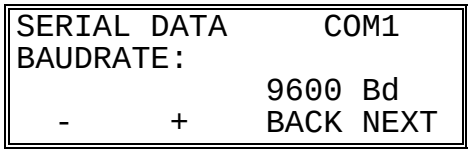
The print format indicates which data report will be issued at the interface (readout).



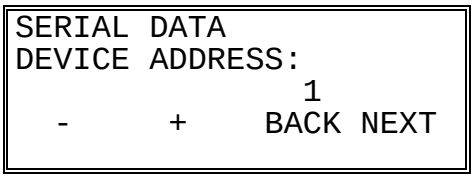
By pressing the **PRINT** key, a printout according to the selected print format is released. To interrupt a running printout, please press the **BACK** key.



After the set time has elapsed, the selected data report will be released. If set to 0 minutes, the next menu allows a cycle ranging from 0 to 120 seconds. Printouts will be limited and repeated to the print cycle.



This display window allows setting the bit transmission rate. Choose between 300, 600, 1200, 2400, 4800 and 9600 Baud.



This address activates the device using commands to be sent via the serial interface

Note: Interfacing will then be processed only by the respective device.

Print Formats

Print formats are provided by an output spooler. While printing, the normal measurement operation will not be interrupted and the measuring instrument can be operated as usual. Remote Control commands are possible using the second serial interface during printing out the lists via the first serial interface. From the internal memory, sufficient information from the print formats is available. The transmission of all half-hourly mean values over an entire year, including information on date and status, requires approximately 632 Kbytes. At a bit transmission rate of 9600, the transmission process will need approximately 10 minutes.

Print Format Examples:

1) Date, time, status, and concentration of black carbon in ng/m3

```
01-11-16  15:39:38 000000  3762
```

2) Date, time, status, concentration of black carbon, and mass of black carbon in µg

```
01-11-16  15:39:38 000000  3762   0.93
```

3) Date, time, status, concentration of black carbon, mass of black carbon, and air flow rate (l/h)

```
01-11-16  15:39:38 000000  3762   0.93  1000
```

5) Date, time, status, concentration of black carbon, mass of black carbon, air flow rate, last value, and mean values of the concentration of black carbon over 1h, 3h and 24h.

```
01-11-16  15:39:38 000000 3762  0.93 1000  3762  3521  4250 1965
```

6) Measuring network protocol

```
<STX>MD01 002 +3023+01 0000 003 000000 <ETX>3B
```

8) Parameter list

Print Format 8 provides the Parameter List for the Model 5012 MAAP. The parameter list provides all internally stored parameters for the operation and calibration of the Model 5012 MAAP.

It is recommended upon receipt of the Model 5012 that Print Format 8 (Parameter List) be downloaded and kept as a record of the manufacturer's default settings. Upon each calibration, a download of the Parameter List should be performed and kept for record keeping.

Should a warning or error status condition occur, download the Parameter List for review.

```
Thermo Scientific  MAAP  v1.32    SERIAL NUMBER     3   01-11-16
------------------------------------------------------------------------

SIGMA BC:               6.6 m2/g
AIR FLOW l/h            1000
MEASURING CYCLE:        10 min

CONC. REFERRED TO       OPERATING CONDITIONS
STANDARD TEMPERATURE    0 °C

PRINT FORMAT:             8
PRINT FORMAT:             0
PRINT CYLCE:              5 min
BAUD RATE:       Bd   9600
DEVICE ADDRESS:           1

FILTER CHANGE
TRANSM. <       %        20
CYCLE           h       100
TIME           HOURS     24

SENSOR CALIBRATION
  P1,V P1,NP  P2,V P2,NP P3,NP T1,NP T2,NP T3,NP
    45    43   226   465  -649   507   507   166
AIR FLOW             10.09

ANALOG OUTPUTS
OUTPUT ZERO POINT:    4 mA
CBC      0 10000
MBC      0    30
Q-OP   500  1100
T1     -10    30
T2     -10    30
Q-N    900  1100

GESYTEC-PROTOCOL
STATUS OCCUPATION      STANDARD
NUMBER OF VARIABLES           3
CBC MBC Q-OP

END
```

9) Parameter change list: 22 entries

Print Format 9 provides a Parameter Change List. With each Operational or Calibration change, a record is kept as a means of tracking the parameter changes. This is an excellent tool for recalling time and dates of operator interaction, qualifying data and instrument security.

```
Thermo Scientific  MAAP v1.32   SERIAL NUMBER   3   01-11-16
-----------------------------------------------------------------------
PARAMETER CHANGE LIST           No.:   83
01-11-16  15:31 PRINT CYCLE:             10     0
01-11-16  15:31 PRINT CYCLE:              1     0
01-11-16  15:30 PRINT CYCLE:              0    10
01-11-16  15:26 AIR FLOW RATE l/h       500  1000
01-11-16  15:24 AIR FLOW RATE l/h      1000   500
01-11-16  15:11 OUTSIDE TEMPERATURE       0    30
01-11-16  14:39 OUTPUT ZERO POINT:        0     1
.
.
END
```

11 & 19) Logbook: 20 & 1,632 entries

Print Formats 11 and 19 provide a Logbook of events. When the instrument status changes, the new status (including date, time, detailed status code, general status code, concentration, mass, air flow rate, and sensor data) are entered into a logbook. Should an event of interest occur, reviewing the Logbook can provide precise information of the instruments operation. If further defining of the detailed error status is necessary, see Chapter 6, “Troubleshooting.”

```
Thermo Scientific  MAAP v1.32    SERIAL NUMBER    3   01-11-16
-----------------------------------------------------------------------
LOG-BOOK
DATE/TIME       ERROR              STATUS  CBC  MBC Q_PM   T1   T2   T3   P1   P2   P3 Sref   S0
01-11-16  15:30 0000 0000 0000 0000 000000 3377    0  999   21   20   24   27   89 1000 1015  497
01-11-16  15:27 0000 0000 0000 0000 000010 3513    0 1000   20   20   24   27   90 1000 1014  508
01-11-16  15:27 0000 0000 0100 0000 080010 3513    0  941   20   20   24   23  194 1000 1014  509
01-11-16  15:23 0000 0000 0000 0000 000010    0    0  498   20   20   24    6   39 1000 1015  519
01-11-16  15:22 0000 0000 0000 0000 000000    0    0  502   20   20   24    6   39 1000 1015  522
01-11-16  15:19 0000 0000 0000 0000 000002    0    0  971   21   20   24   32   98  999    7    4
01-11-16  15:18 0000 0000 0000 0000 000009    0    0    0   20   20   23   -0    2  985 1021  309
01-11-16  15:18 0000 0000 0000 0000 000089    0    0    0    4    4    5   -0    3  190 1021  308
01-11-16  15:01 0000 0000 0000 0000 000010 3972    4  517   21   20   24    6   37 1000 1016  325
01-11-16  15:01 0000 0000 0100 0000 080010 3972    4  648   21   20   24   15   64 1000 1016  325
01-11-16  15:01 0000 0000 0000 0000 000010 3972    4  519   21   20   24   29   98 1000 1016  326
.
.
END
```

30, 31 & 39) Mean values: 60, 60 & 18,560 entries

In compliance with the measuring interval / cycle set, each measured value that has been calculated and saved in memory can be printed via Print Formats 30, 31 or 39. Print Formats 30 and 39 start without headers, and Print Format 31 is represented below. Print Formats 30 and 39 are usually preferred for later data reduction via spreadsheet applications. Print Format 39 provides data from the expanded memory, over 1 year of 30-minute average data.

```
Thermo Scientific  MAAP  v1.32     SERIAL NUMBER     3   1-11-16
-------------------------------------------------------------------------
MEAN VALUES
DATE/TIME       STATUS CBC[ng/m3]
-------------------------------------------------------------------------
01-11-16  15:58 000000 3189
01-11-16  15:56 000000 3350
01-11-16  15:54 000000 3329
01-11-16  15:52 000000 3305
01-11-16  15:50 000000 3342
01-11-16  15:48 000000 3375
01-11-16  15:46 000000 3400
01-11-16  15:44 000000 3443
01-11-16  15:42 000000 3589
.
.
END
```

40 & 41) Daily mean values: up to 380 lines
Print Format 40 has no header lines.

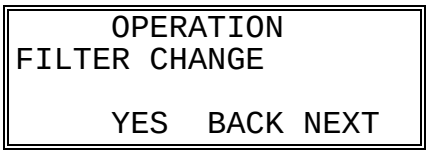
```
Thermo Scientific  MAAP v1.32    SERIAL NUMBER    3   01-11-16
-------------------------------------------------------------------------
DAILY MEAN VALUES
DATE     o.k.%   CBC[ng/m3]
-------------------------------------------------------------------------
01-11-16 100  3564
01-11-15 100  4127
01-11-14 100  3736
01-11-13 100  7314
01-11-12 100  4512
.
.
```

61) Independent of the print cycle, the measured values are output according to the calculation. At midnight, a header line is output as shown in print format 31).

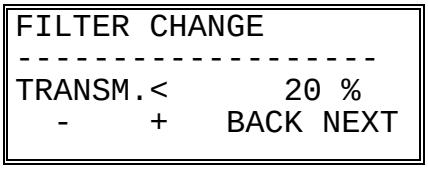
81, 82 & 83) same as 1, 2 & 3), however with an additional header line for each day at midnight.

99) Research applications.

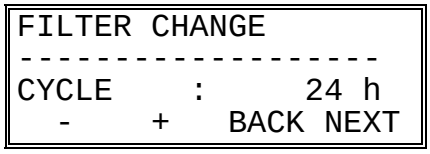
Filter Change Parameters



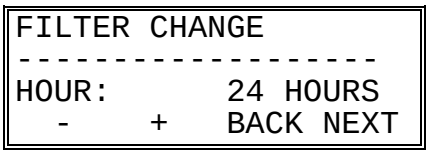
In this part of the Operation Menu, the automatic filter change parameters can be revised. Manual filter changes are not triggered in this menu. The parameters listed correspond to the recommended default settings.



A filter change is automatically triggered when the light transmission reaches 20%. Transmission values less than 20% may create a saturation effect having a consequence that measured values would become less accurate.

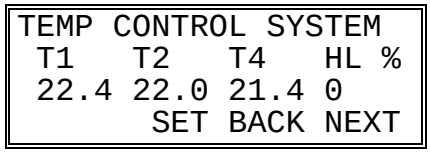


A filter change is triggered if the time since the last filter change has reached the value entered.
Cycle range is 1 to 100 hours.

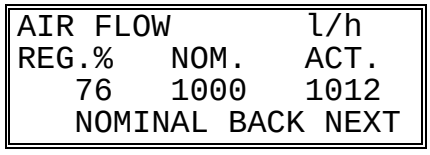


A filter change will be triggered at the set time and the counter for the filter change cycle will be reset. This allows a real-time synchronization of the filter change cycles.
Time range is 0 to 24 hours.
0 HOURS = Filter changes are only cycle dependent
24 HOURS = Filter change at midnight

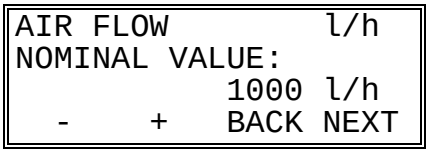
A filter change will also be triggered when the air flow rate falls below **95 %** of the nominal value. In OFFLINE mode, no automatic filter change will be executed.



The temperature control system permits the user to adjust the sample temperature up to 10 °C above the T1 sensor when using the optional heater.



This window displays the nominal and the actual value of the air flow rate as well as the pump controller output in percent of the output range (i.e., 43.8%).



This display serves to enter the nominal value of the volumetric flow rate (Default = 1000 l/h = 16.67 l/min).
Suggested range: 500 – 1200 l/h (8.3 – 20 l/min)

Analog Output Configuration

```
     OPERATION
ANALOG OUTPUTS

      YES BACK NEXT
```

Here, the operator may define the analog output range.
Please note: Analog output selections on the display will always show units of milliamp (mA). Corresponding voltage (V) outputs are achieved by jumper settings. See Chapter 2, "Installation."

```
ANALOG OUTPUTS
OUTPUT ZERO POINT:
            SET: 4mA
 0mA  4mA  BACK NEXT
```

User-selected zero point output of 0 mA/0 V or 4 mA/2 V. Here the user has chosen zero to be a 4 mA (or 2 V) analog output.

```
ANALOG OUTPUTS
CONCENTRATION:
 4mA:        0 µg/m3
  -    +   BACK NEXT
```

User-selected concentration of black carbon (CBC) for the zero point of the analog output range.
Possible settings: -1000 to 1000 µg/m3.
Typically this value would come from a 24-hour zero test.

```
ANALOG OUTPUTS
CONCENTRATION:
20mA:     500 µg/m3
  -    +   BACK NEXT
```

User-selected concentration of black carbon (CBC) for the span point of the analog output range.
Possible settings: 0 to 99,999 µg/m3.

```
ANALOG OUTPUTS
MASS OF BC:
 4mA:         0  µg
  -    +   BACK NEXT
```

Mass of black carbon for the zero point of the analog output range.
Possible settings: -1000 to 1000 µg.

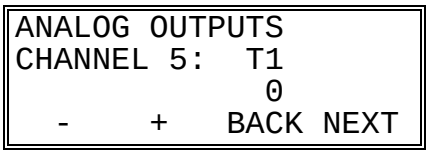
```
ANALOG OUTPUTS
MASS OF BC:
20mA:     2000  µg
  -    +   BACK NEXT
```

Mass of black carbon for the span analog output range.
Possible settings: 0 to 99,999 µg.

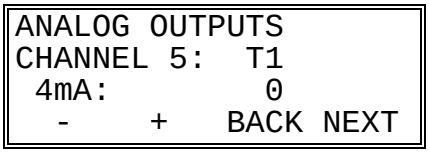
For the following analog outputs of flow rate the optional printed circuit board, ANALOG I/O EXTENSION P/N 42545-1026 will be required.

```
ANALOG OUTPUTS
VOLUME FLOW:
 4mA:         0  l/h
  -    +   BACK NEXT
```

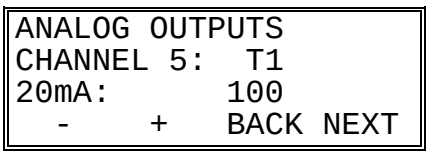
```
ANALOG OUTPUTS
VOLUME FLOW:
20mA:     1000  l/h
  -    +   BACK NEXT
```



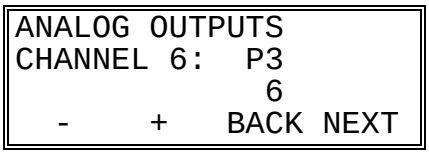
Using the output codes 0 to 11, one of the values T1, T2, T3, T4, P1, P2, P3, REFL or Q-standard can be read out to the analog output channel #5.



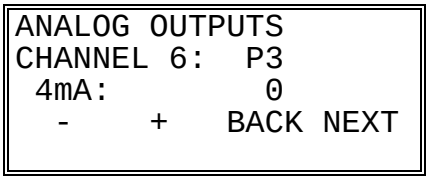
Zero point of the output range: -100 to 99,999.



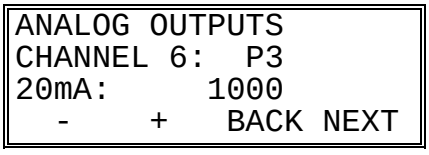
End of the output range: 0 to 99,999.



Using the output codes 0 to 11, one of the values T1, T2, T3, T4, P1, P2, P3, REFL or Q-standard can be read out to the analog output channel #6.

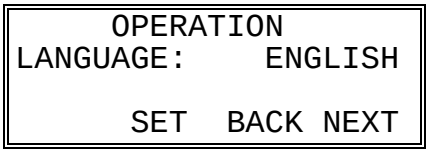


Zero point of the output range: -100 to 99,999.



End of the output range: 0 to 99,999.

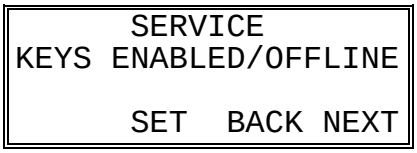
Language



SET: By pressing the **SET** key, you can either select German or English to be displayed.

SERVICE MENU

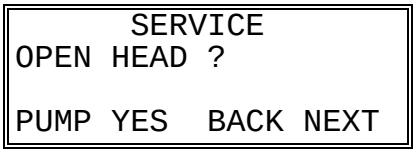
The Service Menu allows the user to carry out hardware and component tests and cable connections.



By pressing the **SET** key, operation can be switched over between keypad and serial interface. Please note that without enabling the keypad, no parameter changes and no actions can be accomplished.

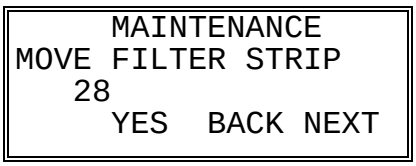
Mechanical Control

This sub-menu enables the measuring head to be opened and the filter transport to be initiated manually.



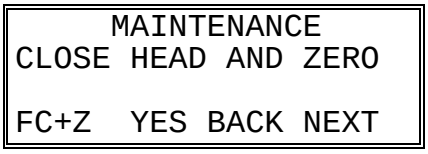
The pump can be switched on and off by pressing **PUMP**. Please make sure not to switch off the pump by pulling off the connecting cable/plug. Otherwise the device assumes that the pump is defective or the tubing was pulled off and consequently sets a corresponding error status.

For the purpose of inserting a new filter tape, it is possible to open the measuring head. The pump is then switched off automatically.

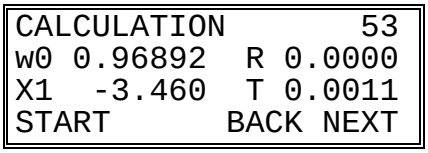


In case the measuring head has been opened, as described in the previous menu, the filter tape transport motor can be switched on by pressing the **YES** key. The number displayed symbolizes the counts of the incremental encoder. This way, it is always possible to check the filter tape for correct transport (e.g., especially after installing a filter tape printer).

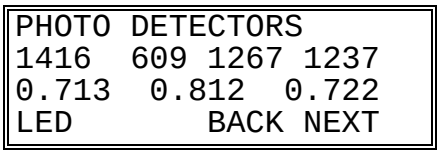
To stop the motor, press the **NEXT** or **BACK** keys. Subsequently, the measuring head should be closed again or a filter change should be performed to continue operation.



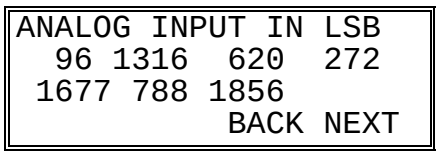
To close the measuring head and zero the instrument press **YES**. The user may also press the **FC+Z** key to initiate a full filter change and zero.



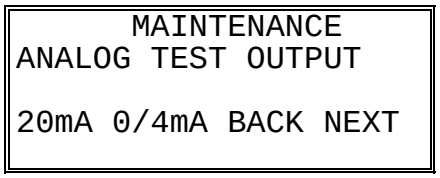
The following screen is a Calculation sub-menu.
Upper right corner: Number of iteration steps
ω_0 : Single scattering albedo of aerosol and filter layers
R : Reflection term
x_1 : ln(Transmittance)
T : Transmission term



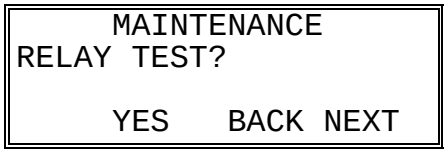
First line (from left to right):
Reference diode / transmittance / reflection under 165° / reflection under 135°
Second line (from left to right):
Transmittance: 0 to 1.000; reflection: 0 to 1.000; angle parameter of the reflection = K * Refl 135° / Refl 165°
*By pressing the **LED** key, the user may toggle the light source on and off. When off, the first line should all go to zero (0).



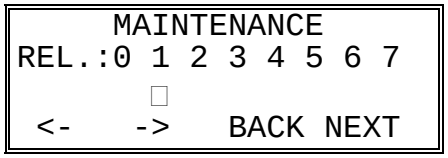
The values supplied by the A/D converter are displayed in the unit LSB (Least Significant Bit).
Bit steps: 0 to 2047



By pressing the respective key, **20 mA** or **0/4 mA,** an equivalent analog output is provided to all analog channels. This allows for adjusting chart recorders connected to the unit and for testing cable connections. When quitting this menu by pressing the **BACK** or **NEXT** key, the measured values will be again output to the analog interfaces. **Corresponding voltages apply.**



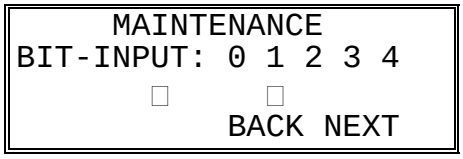
This option enters the relay test mode.
To go on to the next menu point, simply press the **YES** key.



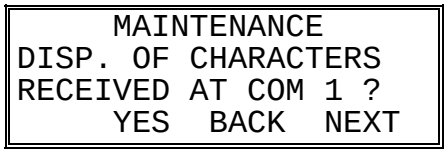
All relays (except the one being marked by a box under the relay number) pick up independent of the current status. By means of the **<-** **->** keys it is possible to make sure that one of the relays is released. Relays 0, 1 and 2 are located on the base plate and represent the following status:

Relay 0: Maintenance or calibration
Relay 1: Exceeding a limit value
Relay 2: Failure/error

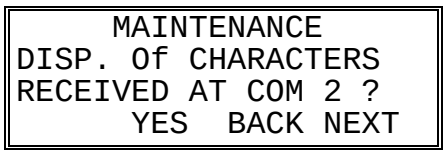
The remaining relays are on the printed circuit board BIT I/O EXTENSION and are primarily used together with the 50-pin measuring network connection. Herewith, it is also possible to check and test cable connections and subsequent processing devices.



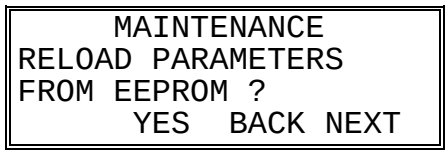
This display shows the state of the input bit.
0: Triggers a filter tape change via switch contact
1-4: Bit I/O extension (50-pin network connection)
Box: Level at the input latch D21: Low
No box: Level at the input latch: High
Bit0: Standard I/O filter change release by closing the switch. A box appears when the switch is closed.
Bit1 - 4 and the 50-pin meas. network connections:
A box appears when the switch opens.
The function associated is not released, if the keyboard has been enabled.
The box below the word INPUT symbolizes the zero point of the cam of the opening/lifting mechanism: If the box exists, this means that the head is open. If there is no box displayed, the head is closed.



Once the **YES** key is pressed, the display will become blank. The data received at the data interface COM 1 will then be represented on the display. However, commands are no longer executed. Pressing the two keys at the right hand side (which then will be no longer subtitled) continues with the dialog and the interface again has its normal function. This function allows for testing of cable connections, interfaces and software functions of the host computer.



The procedure described for COM 1 can be also applied to the interface COM 2.



After the parameters have been set, the values can be saved to the EEPROM in the Calibration Menu. From the EEPROM the parameters can also be reloaded. This function may be useful to restore the initial state after having changed the value, e.g., for test or maintenance purposes. Reloading the parameters from the EEPROM is done automatically each time when an error is detected in the battery-buffered RAM after switching on the monitoring device.

CHAPTER 4
CALIBRATION

This chapter describes the procedure for performing the necessary sensor calibrations of the Model 5012.

EQUIPMENT REQUIRED

Specialized equipment is needed to calibrate the Model 5012 for temperature, barometric pressure, and volumetric flow measurements. The following equipment should be used:

• A thermistor or thermocouple thermometer capable of measuring ambient temperatures in a range of -30 to +45 ^{o}C, readable to the nearest 0.1 ^{o}C. This thermometer should be referenced to within an accuracy of ±0.5 ^{o}C to NIST-traceable precision thermometers. Multiple thermometers may be used to cover the temperature range as long as each thermometer meets the accuracy and readability specifications described above.

• A barometer capable of measuring barometric pressure over a range of 600 to 800 mm Hg (80 to 106 kiloPascals [kPa]) and readable to the nearest 1 mmHg. At least once a year, this barometer should be calibrated to within ±5 mmHg of a NIST-traceable barometer of known accuracy.

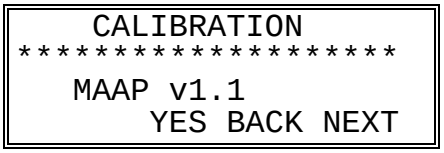
• Flow rate measurement equipment (transfer standards) capable of calibrating, or verifying, the flow rate measurement with an accuracy of ±2 percent. This flow rate standard must be a separate, stand-alone device. It must have its own certification and be traceable to a NIST primary standard for volume or flow rate. Dry-piston meters and bubble flow meters should only be used under controlled laboratory conditions. Ambient field measurements should use a NIST-traceable low-pressure drop orifice/venturi flow meter.

• Tubing, T-Connectors, syringe, and digital manometer for differential pressure sensors.

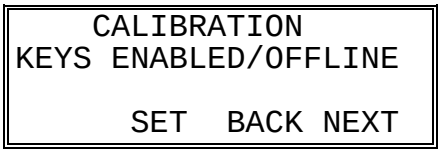
PRE-CALIBRATION

Prior to calibration, be sure the Model 5012 is operating properly. The Model 5012's internal diagnostics makes this a quick and simple process. Turn on the instrument and allow it to stabilize for one hour prior to calibrating. Perform the service checks of Chapter 5, "Preventive Maintenance." Select the operational parameters for the Model 5012 (filter change, analog output, etc.).

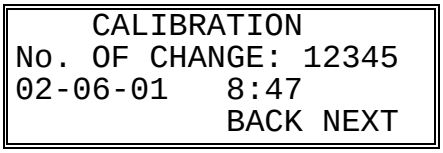
CALIBRATION MENU



In this mode the BC mass, the air flow rate, the temperature, and pressure sensors are calibrated. Correct calibration of these parameters is necessary to accurately record the BC particulate concentration.

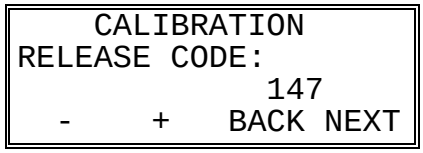


By means of the **SET** key, the monitoring device is operated via keyboard or via serial interface. Without the operation being enabled, it is neither possible to change parameters nor to trigger any actions.



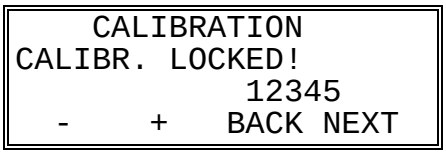
This display shows the running number of the parameter change or calibration including date (yy-mm-dd) and time (hh:mm). Each time a parameter is changed or a calibration is carried out, the value of the counter is incremented and the current date is entered.

The Model 5012 is equipped with a ring-type memory (LIFO) where the number of change, date, type of change, old and new values are entered.

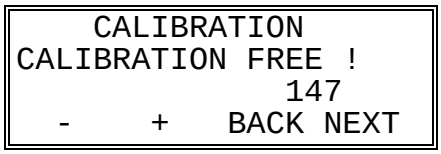


In order to carry out a calibration, it is necessary to first enter the correct release code, **147**.
If there has been no key depression within 4 minutes, or if the device is switched to ONLINE mode, the keypad will be locked.

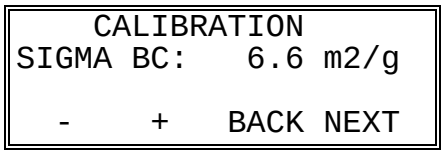
Incorrect Code:



Correct Code:



After having entered the calibration code, the operating status bit calibration is set.



The scattering cross-section of black carbon influences the concentrations measured. It is either determined by an independent measurement or adjusted by comparing it to the basic method. The unit for the scattering cross-section is [m^2/g]. The **-** and **+** keys will only appear with the calibration function being enabled.

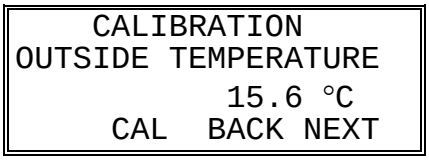
6.6 m^2/g is the default σ_{BC} based on the research of Dr. Andreas Petzold.

Sensor Calibrations

To calibrate the temperature, pressure and flow rate sensors, simply enter the value indicated by a NIST-traceable precision reference unit. The Model 5012 then adopts these values. The calibration values are stored and protected against a loss through a power failure, with checksum in the battery-buffered RAM. The calibration values can be additionally saved to the EEPROM (backup function). The values in the EEPROM will be automatically loaded in case of a RAM error or they can be loaded manually in the Maintenance menu. As far as the temperature sensors and the barometer are concerned, a one-point-calibration should be sufficient. For the two differential pressure sensors, responsible for the air flow rate measurement, calibration of the zero and span point (slope) will be required. All temperature and pressure sensors should be calibrated first prior to calibrating the flow rate.

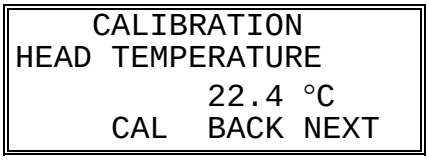
The outside temperature sensor cable must be connected to the female connector marked "SENSORS" (#14, Figure 2-2).

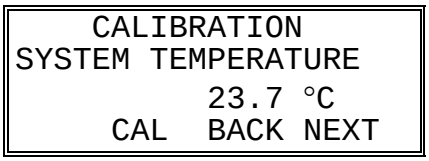
Temperature



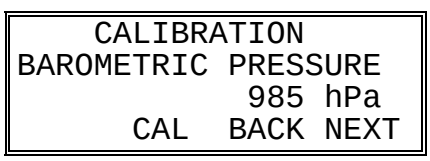
The measured value is displayed. To enter the reference value, press the **CAL** key and then the **+**,**-** keys. The value will be accepted by pressing the **NEXT** key. Reference measurements are made by inserting the reference probe into an attached or nearby naturally aspirated radiation shield.

The same calibration procedure is also valid for the following sensors and can be referenced to shelter temperature if the Model 5012 has been equilibrated for approximately 1 hour with no flow rate. Otherwise, the Head Temperature may reflect the temperature of the incoming sample aerosol.





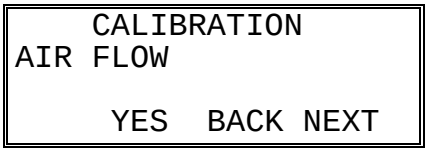
Pressure



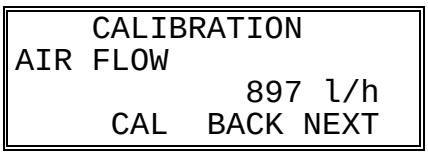
Enter the absolute barometric pressure on site (make sure not to use the pressure that refers to sea level!). If local airport data is being used, be sure to correct for elevation.

Note: (hPa = in Hg x 33.7685)

Flow Rate Calibration



This is the sub-menu used for the air flow rate calibration.

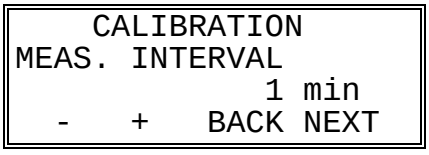


The volumetric flow rate is initially indicated as measured by the Model 5012. Press **CAL** to change the air flow rate calibration coefficient. Thereafter, enter the actual air flow rate measured by a reference instrument and press **NEXT**. Allow 30 seconds between indicated air flow adjustments. Repeat as necessary until corresponding reference and Model 5012 flow rate values agree within 2%. (note: 16.67 l/m x 60 = 1000 l/h).

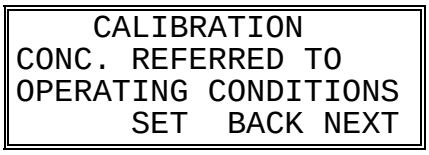
Please be aware of the fact that the air flow calibration always has to be performed last, as a succeeding temperature and pressure sensor calibration would also have an impact on the air flow calibration.

Parameter Configuration

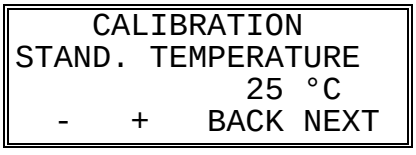
In the following menus, the user may set parameters that are important for the measurement operation.



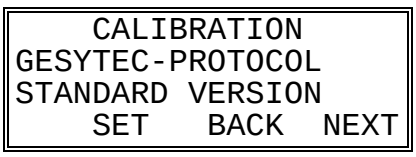
Readout interval for the concentration of black carbon. It may be selected between every: 1 min / 5 min / 10 min / 30 minutes.



To calculate the concentration values, either the volume according to the operating conditions or the volume referred to standard conditions (STP) is used.



The standard temperature can be selected at choice and should range between 0 °C and 100 °C. Most ambient applications use either 20 °C or 25 °C as a standard temperature.



German Network Applications Only. Free parameterization of the RS 232 Gesytec-protocol (Bavaria/Hessia). STANDARD VERSION: corresponds exactly to the status occupation as described in the manual. I-N COMPATIBLE: corresponds to the standard version of the former FH 62 I-N.

```
GESYTEC-PROTOCOL
NUMBER OF VARIABLES
              3
  -    +  BACK NEXT
```

This display shows the number of variables transmitted (here: 3). The number may range from 1 to 6.

```
GESYTEC-PROTOCOL
CBC Q-OP T1

  -    +  BACK NEXT
```

The following can be selected for European installations:

CBC: Concentration of black carbon
MBC: Mass of black carbon
Q-OP: Air flow (referred to operating conditions)
Q-N: Air flow (referred to standard conditions)
T_1: Outside temperature
T_2: Temperature inside the measuring head
T_3: Temperature of the entire system/device
T_4: Temperature of the heater tube
P_1: Orifice differential precision
P_2: Vacuum under filter tape
P_3: Barometric pressure
REFL: Reflective measurement

The variable that is currently being changed will be is blinking on the display.

```
WRITE PARAMETERS
INTO THE EEPROM ?

      YES  BACK NEXT
```

All parameters, dates and calibration data are written into the EEPROM. These data are reloaded, either in case an error is detected in the battery-buffered RAM when switching the mains switch or by simply giving the respective command via keyboard entry in the Service Menu.

```
EEPROM WRITE O.K.

           BACK NEXT
```

```
EEPROM ERROR !

           BACK NEXT
```

The system indicates whether the writing process has been successful or whether a write/read error has occurred. It should also be noted that any Operation Menu changes (see Chapter 3, “Operation and Service”) should also be saved to EEPROM. If a power outage should occur, Operation Menu changes will revert back to prior settings.

After all calibrations are completed, the keypad may be disabled, and normal operation should continue. Normally a filter change and zero (**FC+Z**) is usually activated after a calibration.

CHAPTER 5

PREVENTIVE MAINTENANCE

This chapter describes the periodic maintenance procedures that should be performed on the Model 5012 to ensure proper, uninterrupted operation. Certain components such as the sample pump and filter tapes have a limited life and should be checked on a regular basis and replaced as necessary. Other operations, such as annual optics cleaning and periodic checks on the calibration of the pressure and temperature sensors should also be performed. What follows is a check and/or cleaning procedure for these elements. Replacement procedures for components found to be defective by these checks are given in Chapter 7, "Servicing."

CAUTION: Some internal components can be damaged by small amounts of static electricity. A properly grounded antistatic wrist strap must be worn while handling any internal component. For more information about appropriate safety precautions, see Chapter 7, "Servicing."

SPARE PARTS

Table 5-1. Recommended Spare Parts

Part Number	Description
FH111	Filter Tape Roll
FH153C14	Pump Repair Kit for FH180 and FH180-1 Pumps; includes SM169001042 Set of 3 Carbon Vanes and KT144248920 Set of 2 PVC Separators
SM169001042	Set of 3 Carbon Vanes for FH180, FH180-1 and 425452061 Pumps
KT144248920	Set of 2 PVC Separators for FH180 and FH180-1 Pumps
FH153-01	Pump Repair Kit for 425452061 Pump; includes SM169001042 Set of 3 Carbon Vanes and KT144248925 Set of 2 PVC Separators
KT144248925	Set of 2 PVC Separators Only for 425452061 Pump
425452065	110-240V, 50/60Hz Vacuum Pump
KT169001023	Pump Repair Kit for 42542065 Pump; includes set of 5 Carbon Vanes
KT169001024	Pump Protection Filter

MAINTAINING THE SAMPLE VACUUM PUMP

A rotary vane pump with a dry rotor is used as a source of vacuum. The pump performance is excellent, with minimal heat and noise generation. Only a few maintenance items are required, even when running continuously. The pump can be operated without the need for installing additional filters since the air delivered to the pump is already free from any particulate matter. However, minor amounts of carbon dust may be exhausted from the pump operation and should be filtered if indoor air is being measured.

By default, the air flow rate is set to 1000 l/h (16.67 l/min) with a ± 5 % tolerance. When measuring black carbon the pump can be set between 500-1200 l/h (8-20 l/min), but must be set to a corresponding flow rate of any size selective inlet. Nevertheless, if the Model 5012 cannot reach the desired nominal flow rate, a filter change will be performed automatically under the assumption that the filter spot may have become clogged. An excellent indicator of pump performance is achieved by reviewing the % Power to the pump in the Operation Menu. If the flow rate of the Model 5012 is below the nominal set point and the pump power is very high (>95%), then the user should check and tighten the fittings. Otherwise, if all fittings are tight and pump wear is suspected, then the user should replace the vanes (See Chapter 7, “Servicing”).

Maintenance of the rotating pump has to be carried out in accordance with the special instructions given by the pump manufacturer.

As the pump usually only operates with pre-filtered air, abrasion of the carbon vanes is only minor. The service life of a set of carbon vanes amounts to more than 1 year of operation. For this reason, one should either check the carbon vanes at intervals of 2,000 – 3,000 hours, which corresponds to a 3-month cycle or change them once a year (See Chapter 7, “Servicing”).

CHECKING THE AIR FLOW

To check and calibrate the air flow rate, please see the detailed description given in Chapter 4, "Calibration." For this purpose, a flow transfer standard is needed to determine and calibrate the air flow (preferred flow meters can be supplied by Thermo Fisher Scientific as maintenance accessories).

Typically it is recommended to visit the monitoring site biweekly to perform a flow check for control charting purposes. Flow audits can be done once per quarter. If the flow rate of the Model 5012 does not deviate by more than ±5% of the auditing standard then no calibration is required except for an annual calibration. A drifting control chart from biweekly flow checks can define for the user what the calibration frequency may be for the instrument and if there is any sensor drift.

Please be cautious of checking flow standards in the field. Typically bubble flow meters and dry piston meters should be limited to laboratory use and are not recommended by Thermo Fisher Scientific as an appropriate flow meter for field conditions.

TEMPERATURE SENSORS

There are three (3) temperature sensors included in the Model 5012. These sensors are the T1 Ambient Sensor, T2 Measuring Head Sensor located just upstream of the filter tape, and T3 System Sensor which measures the temperature upstream of the orifice. The measuring range of these temperature sensors is -30 to 70°C, however the Model 5012 is rated for a temperature range of -4 to 122°F (-20 to 50°C).

Typically it is recommended to visit the monitoring site biweekly to perform a flow check for control charting. Should an error in the flow check be significant (>7%), the error may be caused by one of the temperature sensors. It would also be beneficial to control chart the temperature sensors with each site visit. Furthermore, temperature sensor audits can be done once per quarter. If any temperature sensor does not agree within (±2°C) of the auditing standard then a calibration is required in addition to an annual calibration. A drifting control chart from biweekly checks can define for the user what the calibration frequency may be for the instrument and if there is any persistent sensor drift. Should a temperature sensor need to be replaced, reference Chapter 7, "Servicing."

PRESSURE SENSORS

There are three (3) pressure sensors included in the Model 5012. These sensors are the P1 orifice sensor, P2 pump vacuum sensor, and P3 barometric pressure sensor. P1 measures the pressure differential across an orifice and is used for the flow calibration. P2 measures the vacuum under the filter tape, relative to barometric pressure. P3 directly measures the barometric pressure. P1 and P2 are automatically zeroed with every filter spot change.

Typically it is recommended to visit the monitoring site biweekly to perform a flow check for control charting. Should an error in the flow check be significant (>7%), the error may be caused by one of the pressure sensors (most probably P3 barometric pressure). It would also be beneficial to control chart the P3 sensor with each site visit. Furthermore, P3 sensor audits can be done once per quarter. If the P3 sensor does not agree within ±10 mm Hg of the auditing standard, then a calibration is required in addition to an annual calibration. A drifting control chart from biweekly checks can define for the user what the calibration frequency may be for the instrument and if there is any persistent sensor drift. Should a fatal error occur with a pressure sensor, contact the Thermo Fisher Scientific Service Department.

OPTICS CHAMBER

Best results are obtained when the optics are kept clean. Unless unusual dust storms have recently occurred and apparently interfered with subsequent measurements, the optics chamber should be cleaned once per year by a Thermo certified technician or qualified field personnel.

INLET ASSEMBLIES

The inlet assemblies can include a simple sampling cane, extended down tube, particle size separation devices (cyclone or impactor), and/or ambient 10-micron inlet.

Cleaning schedules and routine maintenance of assembly components (e.g., o-rings) should be established and maintained by the user.

PM2.5 WINS Impactor Cleaning and Inspection

If using the Model 5012 for PM2.5 Black Carbon, disassemble and clean the WINS impactor at least every five sampling days. The PM2.5 WINS impactor is cleaned by separating the upper and lower housings, wiping the upper and lower impactor well clean with lint-free laboratory tissues or a cloth, putting a new filter in the lower impactor well, and adding 1 ± 0.1 ml of impactor oil. The oil should cover the filter uniformly. Reassemble the well and place in the impactor. Preparation time can be saved by preparing several spare impactor wells and storing them in a clean, particulate-free, container until needed.

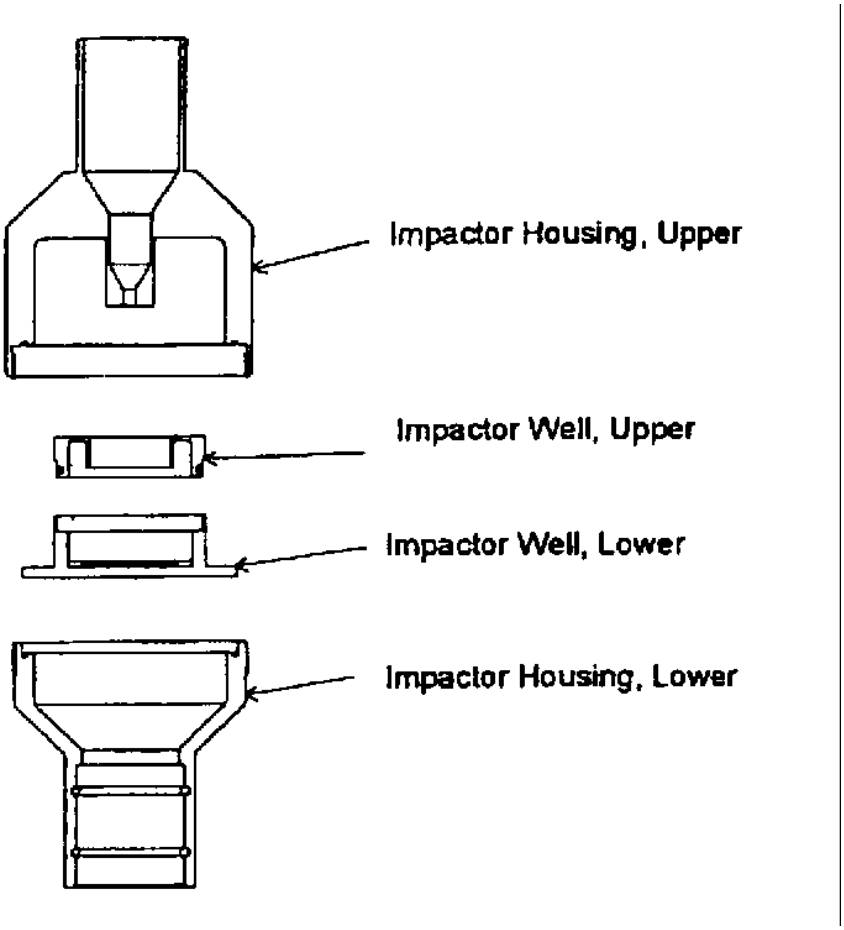


Figure 5-1. Exploded View of PM2.5 WINS Impactor

Once a month, with the impactor assembly open, inspect the interior of the impactor housing, both above and below the impactor well. These areas should be clean and dry. If necessary, clean the areas with a lint-free wipe. On a monthly basis, clean the interior of the impactor nozzle jet using a lint-free pipe cleaner or similar tool. Also monthly, check the o-rings for distortion, cracks, fraying, or other problems and replace as necessary.

Sharp-Cut Cyclone (SCC) Maintenance

If a Sharp-Cut Cyclone is being used for PM2.5 Black Carbon sampling (See Figure 5-2), once every 2-3 weeks the dust pot should be unscrewed, emptied, and cleaned with a lint-free cloth. Once every 3 months, the entire SCC assembly should be inspected and cleaned, o-rings checked for distortion, cracks, fraying, or other problems. Replace o-rings as necessary.

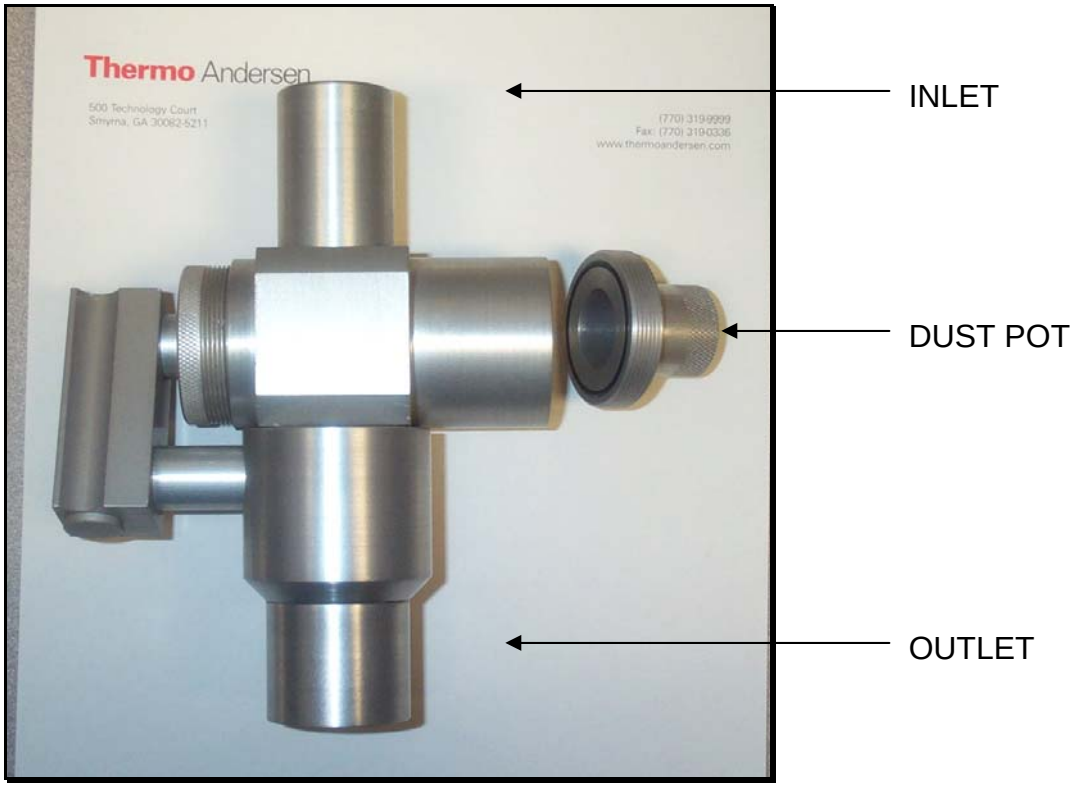


Figure 5-2. PM2.5 Sharp Cut Cyclone

PM10 Inlet

The water collector bottle located on the inlet should be inspected at least every five sampling days (see Figure 5-3). Remove any accumulated water, clean the interior of the bottle, inspect the seals, and replace the bottle in the holder.

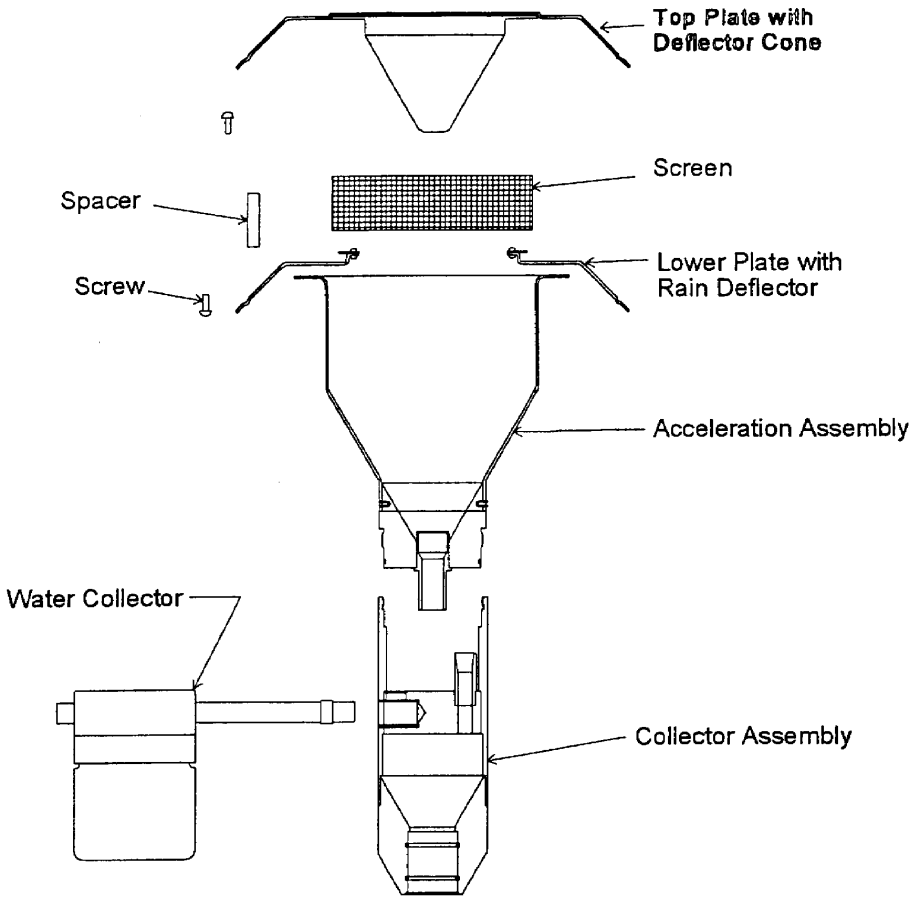


Figure 5-3. PM10 Inlet

Once a month the sampler inlet should be dismantled and cleaned. Mark each assembly point of the sampler inlet with a pen or pencil to provide reference marks during reassembly.

Disassemble the sample inlet unit according to Figure 5-3. If the assembly screws are frozen, apply penetrating oil or commercial lubricant to make removal easier. Clean all interior surfaces and the bug screen with a general purpose cleaner or compressed air, paying particular attention to small openings and cracks. Cotton swabs and/or a small brush are helpful. Completely dry all components.

Also monthly, check the o-rings for distortion, cracks, fraying, or other problems and replace as necessary. Apply small amounts of grease to the o-rings before assembling the unit.

Reassemble the unit in accordance with the previously scribed match marks. Particular care should be taken to ensure that all o-ring seals are properly seated and that all screws are uniformly tightened.

CHAPTER 6

TROUBLESHOOTING

The Model 5012 has been designed to achieve a high level of reliability. Only premium components are used, thus complete failure is rare. In the event of problems or failure, the troubleshooting guidelines presented in this chapter should be helpful in isolating the fault(s). The Service Department at Thermo Electron, Environmental Instruments can be consulted in the event of problems at (508) 520-0430. In any correspondence with the factory please note the serial number of the instrument.

CAUTION: Some internal components can be damaged by small amounts of static electricity. A properly grounded antistatic wrist strap must be worn while handling any internal component. For more information about appropriate safety precautions, see Chapter 7, "Servicing."

TROUBLESHOOTING GUIDE

MALFUNCTION	POSSIBLE CAUSE	ACTION
Does not start up	No power	Check that the instrument/pump is plugged into the proper source (100/120V or 220/240V)
		Check instrument fuse
	Power supply	Check voltages from power supply
	Digital electronics defective	Check that all boards are seated properly
		Replace with spare boards to isolate the problem

MALFUNCTION	POSSIBLE CAUSE	ACTION
Cannot change parameters	Keypad is not enabled	Enable keypad through menu
No automatic filter change	Reel nuts not tight	Tighten reel nuts
	No more filter tape	Replace with new filter tape
	Filter not properly adhered	Adhere filter tape to take-up reel and wind over itself once
	Optical tape counter defective	Replace optical tape transport sensor
	Filter tape transport drive motor defective	Replace motor
% transmission is constantly elevated	Transmission sensor cable unplugged	Check connections
	Transmission sensor defective	Replace sensor
Back scatter sensor inoperative	Sensor cables loose	Check sensor cables
LED source inoperative	LED cable unplugged	Check connection
	LED defective	Replace LED
Pressure transducer does not hold calibration or is noisy	Pressure transducer defective	Replace pressure transducer

MALFUNCTION	POSSIBLE CAUSE	ACTION
Temp. Sensor malfunction	Loose or broken cable or bad sensor	Repair cable or replace sensor
Run output noisy	Recorder noise	Replace or repair recorder and/or leads.
	Sample BC concentration varying	Run Model 5012 on a zero filter - if quiet, there is no malfunction
	Foreign material in optical bench	Clean optical bench
	Digital electronics defective	Replace board with a spare board
Analyzer does not calibrate properly	System leak	Find and repair leak
	Pressure or temperature transducer(s) out of calibration	Recalibrate pressure or temperature transducer(s)
	Digital electronics defective	Replace one board at a time with a spare board to isolate the defective board
Analog test ramp	Faulty recorder	Replace recorder
	Span output on	Turn span off
	Digital electronics defective	Replace board with a spare board

MALFUNCTION	POSSIBLE CAUSE	ACTION
Display is off	Wrong contrast setting	Adjust potentiometer on board
	LCD cable loose	Check connection and cable integrity
	LCD defective	Replace display

STATUS MESSAGES

The status messages serve to inform and alert the user of the instrument operation. Among these features are the operating status, warning status, and error messages.

The status message can be reviewed in the Main Menu and through the internal memory data download. In case there is no status message present, the measuring instrument is in the normal operation mode and the green LED "READY" will be illuminated.

The yellow LED "STATUS" stands for an operating and/or warning status.

The red LED "ERROR" will illuminate in case of an instrument error.

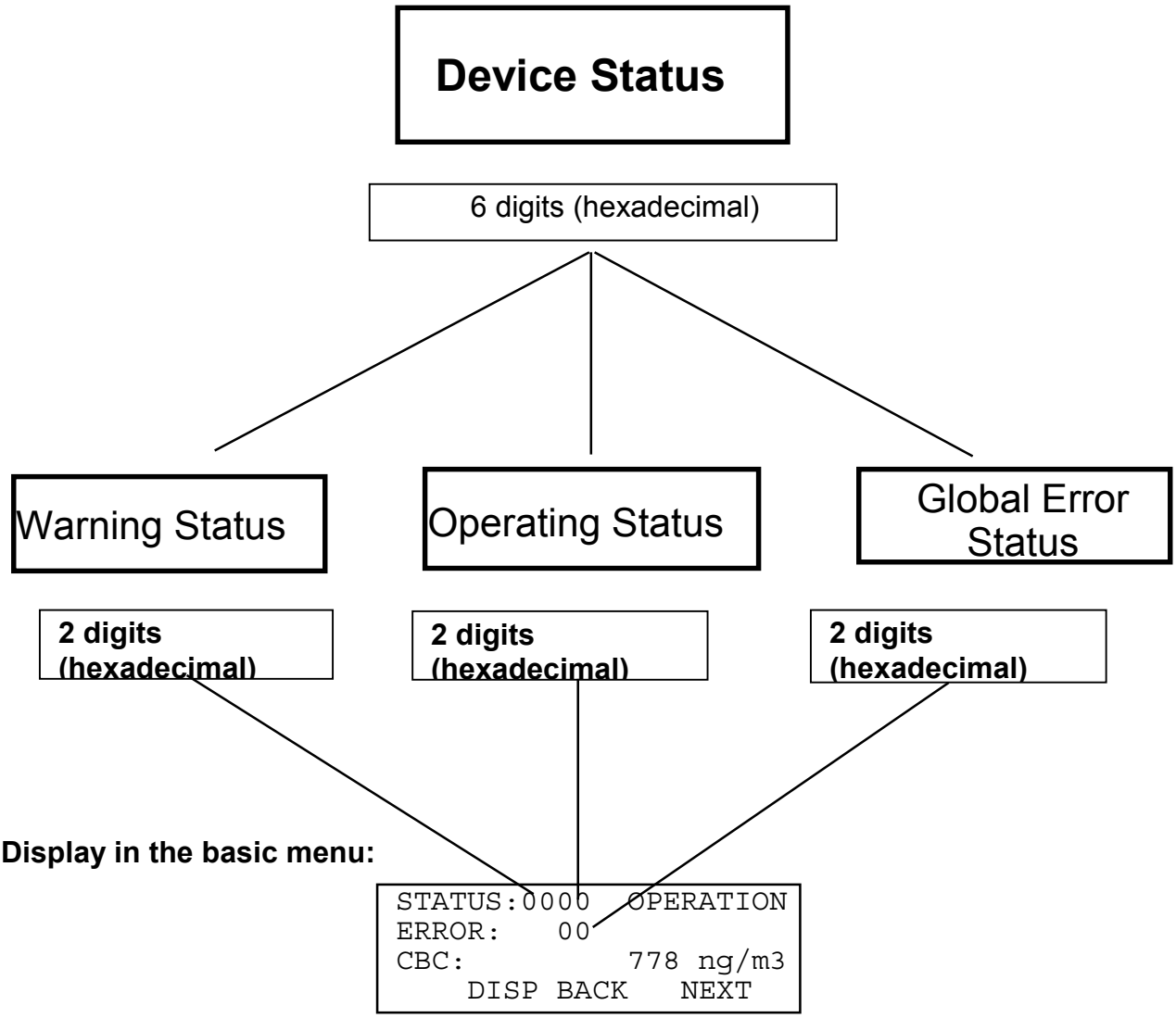
The general status message is abbreviated and represented as a 6-digit hexadecimal number. Each of the 6 characters represents up to 4 independent conditions. The eight global error status bits each represent a group of eight status bits. Consequently, a total number of 64 errors independent of each other can be distinguished allowing the user to pin point a specific error.

With the measuring instrument being in the normal error-free measurement operation, the status will show the value 000000.

Global status: 6 characters, each one consisting of 4 bits, characters 0..F
In the following section is a list of the most important status displays. The status, however, can occur also in various other combinations.

Status Concept and Structure of the Model 5012

This section interprets the Operational, Warning and Error Status codes that may be indicated by the Model 5012.



Decimal- and hexadecimal system

dec.:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
hexadec.:	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

Warning and Operating Detailed Status Reports

Warning Status

Characteristic	Significance
01	LED too weak
02	free
04	free
08	free
10	free
20	free
40	free
80	free

Operating Status

Characteristic	Significance
00	Normal measurement operation
01	Filter change (mechanical)
02	Zeroing the sensors
04	free
08	Pump off
10	Manual operation (off-line, keyboard enabled)
20	Calibration enabled
40	free
80	Mains on (reset after filter change)

Structure of the Status Concept

Note: The characteristic numbers of the detailed status messages are added and thus form the warning as well as the operating status.

Examples:

STATUS:	Significance	
0011	0010	Manual operation,
	0001	Filter change (mechanical),
0082	0080	Mains on (reset after filter change),
	0002	Zeroing (mass)
00A9	0001	Filter change (mechanical),
	0008	Pump off
	0020	Calibration enabled
	0080	Mains on (reset after filter change)

Note: Below are the combinations of potential added status codes and their breakdown. In the STATUS example above, recognize that the "A" in 00A9 shows a combination of 20 and 80 for the Operating Status. Do not confuse this with a 02 and 08 for Operating Status. The positioning of the alphabetical character is key to defining which codes the instrument is reporting. Being able to recognize these subtleties will allow the user to easily define and troubleshoot the Model 5012 as necessary. Below is a matrix of alphanumeric combinations.

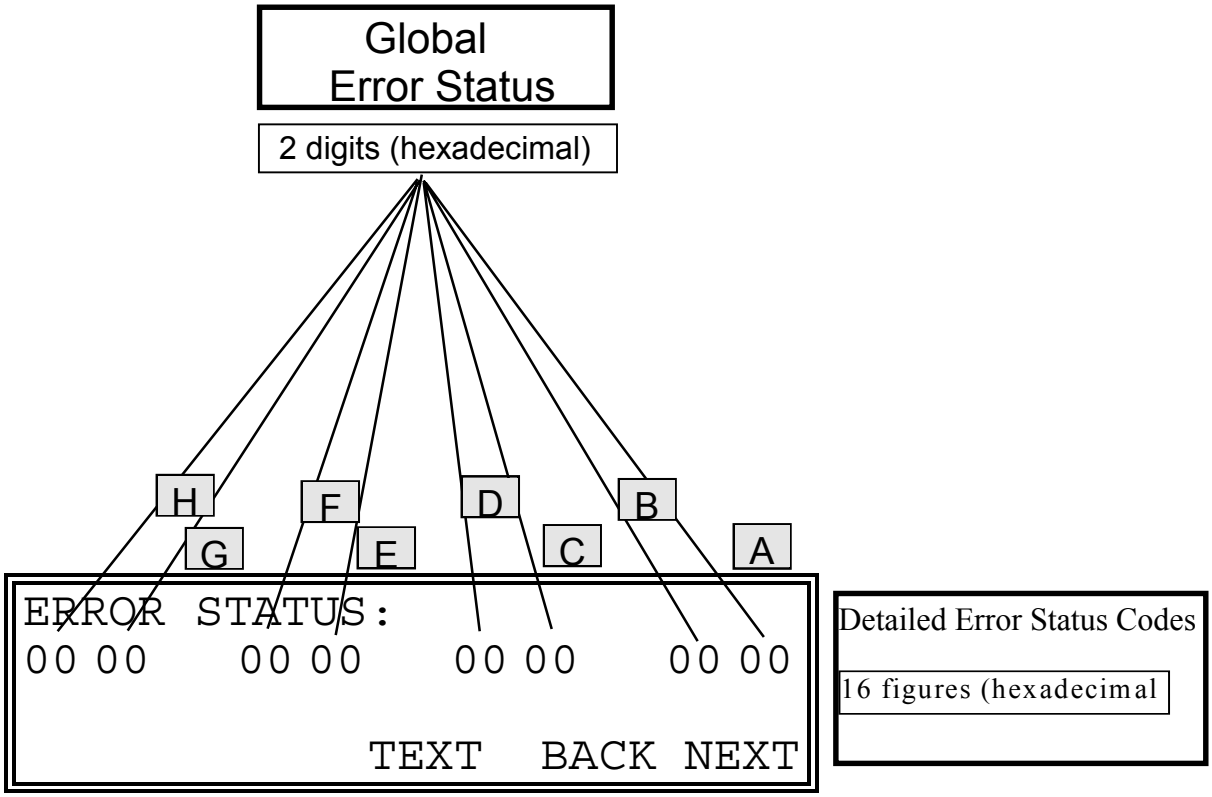
0	1	2	3 = 2 + 1
4	5 = 4 + 1	6 = 4 + 2	7 = 4 + 2 +1
8	9 = 8 + 1	A = 8 + 2	B = 8 + 2 + 1
C = 8 + 4	D = 8 + 4 + 1	E = 8 + 4 + 2	F = 8 + 4 + 2 +1

Detailed Status Messages

From the Main Menu, a Global Error Status appears as a 2 hexadecimal figure. Below are the codes and general definitions. Each code should be interpreted by reviewing the detailed error status codes.

Code	Global Error Status Definition	Field
01	Sum status of the data and program memory	A
02	Sum status of the mechanical components	B
04	Sum status of the pressure sensors	C
08	Sum status of the air flow regulation	D
10	Sum status of the photo detectors	E
20	Sum status of the temperature measurement	F
40	free	G
80	free	H

The following break down of the Global Error Status indicators to a Detailed Error Status can be obtained by pressing the **DISP** key once and the **NEXT** key 4 times from the Main Menu.



Detailed Error Status

0000 0000 0000 00**00**

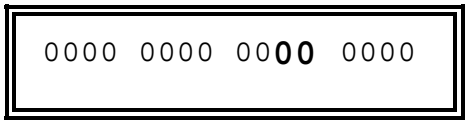
A Sum status of the data- and program memory (memory error**):**

Characteristic	Significance
01	PROM error (FLASH-EEPROM)
02	RAM error
04	SaveRAM error (backup battery empty)
08	EEPROM write/read error
10	free
20	free
40	free
80	free

0000 0000 0000 **00**00

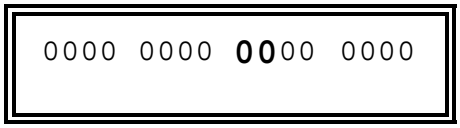
B Sum status of the mechanical components:

Characteristic	Significance
01	free
02	free
04	free
08	Suction chamber negative pressure <10 hPa (if pump runs !)
10	Lifting position: opening of the filter tape gap has not been recognized
20	Filter tape fissure: no filter tape transport has been recognized
40	free
80	Filter change condition already met again immediately after a filter change has been carried out



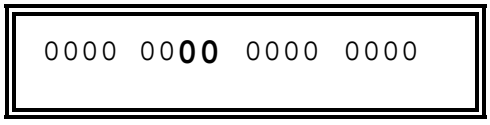
C Sum status of the pressure sensors:

Characteristics	Significance
01	Orifice pressure sensor negative or over range
02	Pump vacuum pressure sensor negative or over range
04	Sensor for barometer negative or over range
08	free
10	free
20	Orifice pressure < 1hPa
40	free
80	free



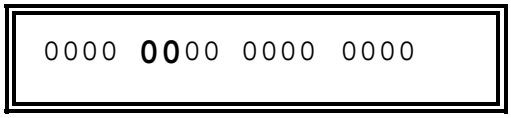
D Sum status of the air flow regulation:

Characteristics	Significance
01	Deviation > 5 %
02	Air flow regulator completely open
04	Air flow regulator completely closed
08	free
10	free
20	free
40	free
80	free



E Sum status of the photo detectors:

Characteristics	Significance
01	Reference signal negative or over range
02	Transmission signal S0 negative or over range
04	Reflection signal S165 negative or over range
08	Reflection signal S135 negative or over range
10	Signal too low with the LED being ON
20	Dark signal too high with the LED being switched off
40	free
80	free



F Sum status of the temperature measurement

Characteristics	Significance
01	Ambient temperature sensor T_1 short circuit
02	Ambient temperature sensor T_1 interruption
04	Measuring temperature sensor head T_2 short circuit
08	Measuring temperature sensor head T_2 interruption
10	System temperature sensor T_3 short circuit
20	System temperature sensor T_3 interruption
40	free
80	free

Overlay of Several Status Messages

Note: The characteristic numbers of the detailed error status messages are added and thus form the detailed error status and the global error (failure) status.

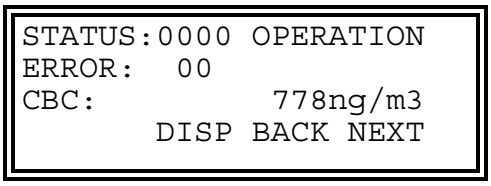
Examples:

ERROR STATUS:

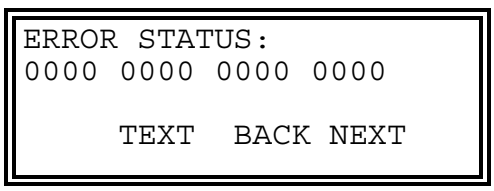
01:	0000 0000 0000 0004	SaveRAM error (backup battery empty)
02:	0000 0000 0000 3000	Lifting position: opening of the filter tape gap has not been recognized Filter tape fissure: no filter tape transport has been recognized
04:	0000 0000 0001 0000	Orifice pressure sensor negative or over range
08:	0000 0000 0300 0000	Deviation > 5% Air flow regulator completely open

Status Messages on the Display

Basic menu:



Main menu DISP:



CHAPTER 7
SERVICING

This chapter explains how to replace the Model 5012 filter tape & carbon vanes of the vacuum pump, and also update the software. Fault location is accomplished in the preceding chapters of "Preventive Maintenance" and "Troubleshooting." For additional service assistance, see "Service Locations," later in this chapter.

SAFETY PRECAUTIONS

Some internal components can be damaged by the discharge of static electricity. To avoid damaging internal components, follow these precautions when performing any service procedure:

- Wear an antistatic wrist strap that is properly connected to earth ground (note that when the analyzer is unplugged, the chassis is not at earth ground)
- If an antistatic wrist strap is not available, be sure to touch a grounded metal object before touching any internal components
- Handle all printed circuit boards by the edges
- Carefully observe the instructions in each procedure

FILTER TAPE REPLACEMENT

As soon as the filter tape on the filter roll is empty, a replacement of the roll is necessary. The filter tape is usually replaced every year, but this can also depend on the non-standard operational parameters chosen by the user or the loading per filter spot. In high concentration areas, more frequent filter changes can occur due to higher loading. As a basis for an estimation of this time, the reference can serve that ~40 m of tape per roll is sufficient for approximately 800-900 single measurements. Due to the uncertainty of filter tape life in higher concentration areas, checking the filter tape every 6-9 months may be warranted. To change the filter tape, follow the instructions in Chapter 2, "Installation."

CARBON VANE REPLACEMENT

Vane replacement should be done outdoors. Failure to do so may introduce carbon particles into the air and damage electronic equipment. Before servicing, the vacuum pump must be switched off and secured from any accidental start-up. See Figure 7-1.

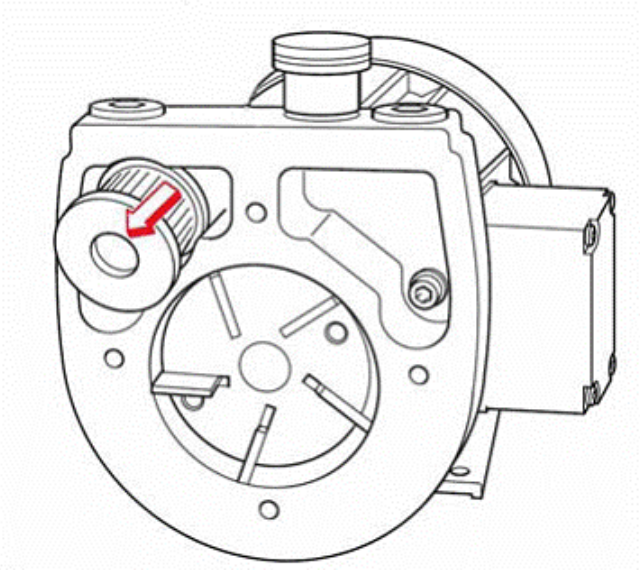


Figure 7-1. Pump Parts Location.

Blow carbon particulate from the vane cavity with an air hose.

WARNING: Avoid breathing in carbon particulate. Use an approved particle filter or respirator.

When installing new vanes, be sure the beveled side points outwards (see Figure 7-2). Reassemble the parts in the reverse order.

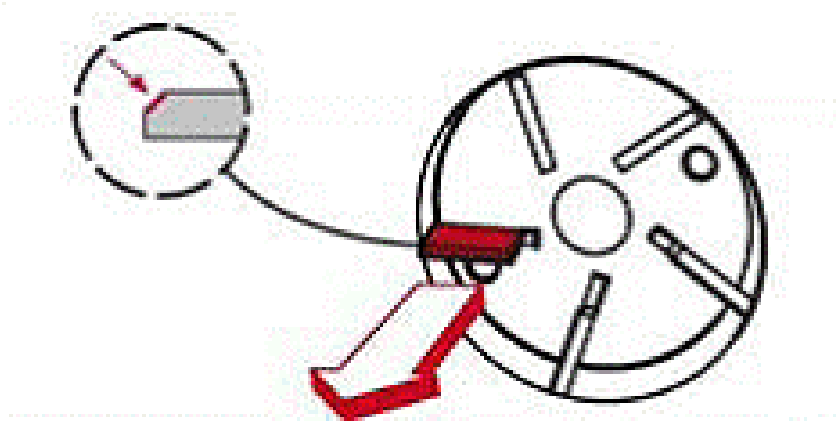


Figure 7-2. Carbon Vane Installation

SOFTWARE UPDATES

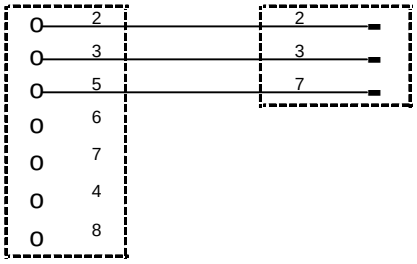
With the Model 5012, the software can be updated either by exchanging the EEPROM or by uploading the program code via the serial interface COM1.
A download of the Parameter List (Print Format 8) should be done prior to any software updates.

The program received first is read and loaded into the "512 Kbytes-RAM extension." Once the data transmission has been completed successfully without error, the program code is written into the Flash-EEPROM.

Loading a new software version

1) Conditions to be fulfilled:

- PC with MS-DOS V3.3 or later
  - Hard disk
  - Floppy disk drive
  - 1 serial interface (COM1)
- Model 5012 with a pre-programmed Flash-EEPROM (D3)
  - 512 Kbytes RAM extension (D4)
  - Plug-in bridge X30 / Pin 1-2 (not to be plugged in the Flash-EEPROM)
- Connecting cable PC (COM1) to the Black Carbon Monitor MAAP (COM1)
- Below is a 9-pin female to 25-pin male cable



PC COM 1 9 Pin — MAAP COM 1 25 Pin

2) Connect the **interface COM1** of the PC with COM1 of the Model 5012.
Subsequently, switch on the devices.

3) Configuring the serial interface COM1 of the Model 5012:

- Print format: 0
- Print cycle: 0 min, 0 s
- Transmission rate: 9,600 baud
- Switch the device to "online" mode

4) Calling the program
Copy both the "UPDATE.EXE" file and the "MASTER.HEX" file into a sub-directory of the hard disk on the PC. Once copied, start the program by typing in "UPDATE." Subsequently, the display shows the following:

```
RECEIVING FLASH DATA
--------------------
2C80
```

Address of the data byte (the address will be also shown on the PC screen)

After successful completion of the data transmission, the flash EEPROM is written.
The display will then show the following message:

```
PROGRAMMING FLASH MEM
---------------------
FFC0
```

After the successful programming, the measuring device starts its operation by performing a "Mains on routine". For around 30 seconds the software version currently installed will be displayed. Then, the device proceeds with the normal measurement operating mode.

In case the check sum test fails (with erroneous data transmission) or if programming of the flash EEPROM does not work correctly (jumper 30 has to be set to PRG on the circuit board), the measuring instrument starts using the old software version.

To cancel a running data transmission, please press the <ESC> key.
If the data transmission does not start immediately, start the program "UPDATE.EXE" again.

5) Checking the parameters
The software update does not have any effect on the parameters of the monitor. Nevertheless, as a precaution you should compare the Print Format 8 parameters with the default values and previous values.

SERVICE LOCATIONS

For additional assistance, Environmental Instruments Division has service available from exclusive distributors worldwide. Contact one of the phone numbers below for product support and technical information.

866-282-0430 Toll Free
508-520-0430 International

CHAPTER 8
THEORY OF OPERATION

MEASUREMENT PRINCIPLE

The illustration provided in Figure 8-1 gives an overview of the measuring head being part of the Model 5012 Multi Angle Absorption Photometer (MAAP) for black carbon monitoring.

The MAAP serves to determine the fraction of elemental carbon suspended in the ambient atmosphere. The principle of determination is based on a combination of the reflectometer method at certain defined scattering angles and the transmission. With this method, also multiple scatterings are taken into consideration. The scientific foundations are described in detail in the publication (originally published in ESPR – Environ Sci & Pollut Res • Special Issue 4 (2002): 78 – 82) by Dr. Andreas Petzold, which can be found in Appendix D, "ARTICLE."

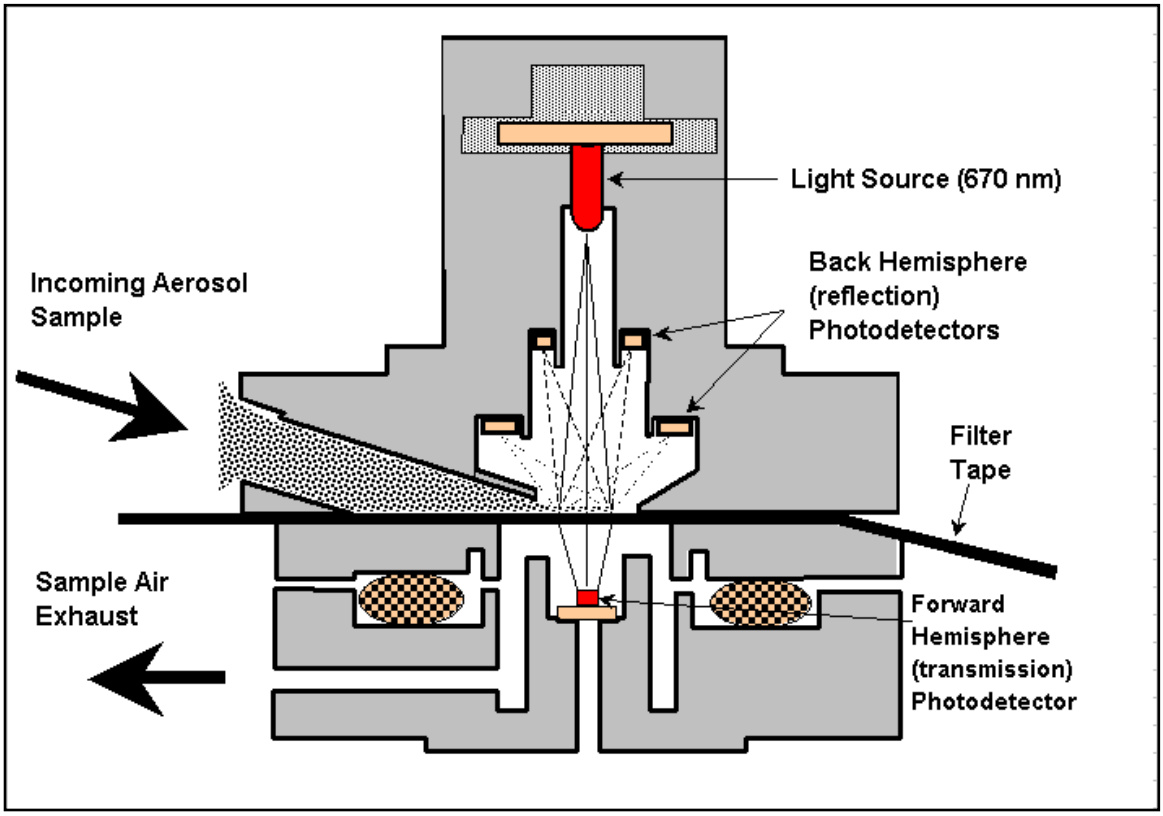


Figure 8-1. Function Principle of the MAAP Monitoring Instrument

CALCULATING MASS AND CONCENTRATION OF BLACK CARBON (BC)

The mass of black carbon is calculated from

$$MBC = (1-\omega_0) * X_1 * Area / \sigma_{BC}$$

Where:

MBC = mass of black carbon

ω0 = single scattering albedo

X1 = ln (transmittance)

Area = area of the dust collecting spot (2.0 cm^2)

σBC = scattering cross section of black carbon (6.6 m^2/g)

The black carbon concentration can be calculated from the following equation:

$$CBC = \Delta MBC / Vol$$

Where:

CBC = concentration of black carbon

ΔMBC = variance of the mass of black carbon

Vol = sample volume

AIR FLOW RATE

When determining the concentration of particulate matter suspended in ambient air by means of any filter sampling method, the precise measurement of the air flow rate is equal in significance to the determination of the mass of black carbon as far as the exactness of the concentration measurement is concerned.

The MAAP Black Carbon Monitor embodies a pressure and temperature compensated air flow rate measuring probe allowing for precise measurement of both, the volumetric air flow and the air flow referenced to standard temperature and pressure conditions (1013 hPa, temperature user selectable).

Air Flow Rate Measurement

With the MAAP Black Carbon Monitor, the differential pressure principle is utilized to measure the air flow rate. After passing the filter tape, the air to be measured passes through an orifice plate. The flow rate is then calculated from the pressure drop measured at the orifice plate. In Figure 8-2, a representation of the flow path and measurement are provided.

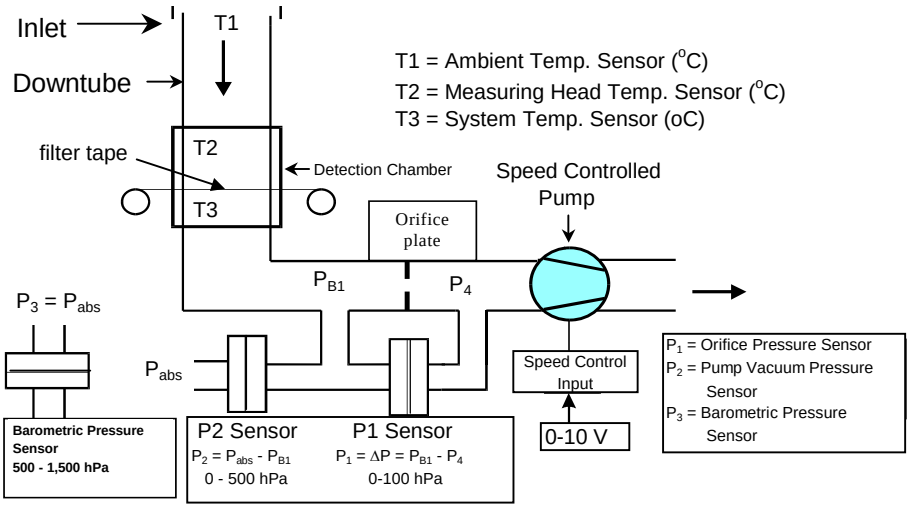


Figure 8-2. MAAP Flow Path and Measurement

Principle of the Air Flow Rate Measurement

If the pressure drop at the orifice plate is low in comparison to the absolute pressure ($P/P_{abs} > 0.95$), the following formula is a good approximation to define:

1. Volume flow at the orifice plate:

$$Q_{Vol} = \alpha * A * \sqrt{\frac{2}{\rho} * \Delta P_1}$$

where:

Qvol = volume flow

α = flow number, takes into consideration the position of the pressure tapping, the speed profile, the ratio between the orifice cross section and the tube cross section. The flow number is a non-dimensional number having

A = orifice cross section

$\Delta P1$ = pressure drop at the orifice plate

ρ = density of the air to be measured, where

$$\rho = \rho_0 * \frac{T_0}{T} \frac{P}{P_0}$$

where:

$\rho 0$ = standard air density: 1.293 kg/m3 (at STP = 1013 hPa, 273K)

T0 = absolute temperature at standard temperature conditions: 273K

T = absolute temperature at operating condition

P0 = absolute pressure at standard pressure condition: 1013 hPa

P = absolute pressure at operating conditions at the orifice plate

2. Volume flow referred to standard conditions:

Pursuant to the general gas laws it follows

$$Q_{Norm} = \frac{T_0}{T} * \frac{P}{P_0} * Q_{Vol}$$

Merging the above equation into it, this results in

$$Q_{Norm} = F * \sqrt{\frac{P}{T} * \Delta P_1}$$

where:

T = absolute temperature at the orifice plate: T = T3 + 273K

T3 = temperature in the suction chamber (system temperature)

P = absolute pressure at the orifice plate (barometric pressure – suction vacuum: P = [P3 - P2])

F = orifice factor (flow rate calibration factor):

$$F = \alpha * A * \sqrt{\frac{T_0}{P_0} * \frac{2}{\rho_0}}$$

The flow rate measurement errors that arise out of an inaccurate sensor calibration are only of less importance: Aligning the flow rate calibration factor compensates possible inaccuracies of the sensor calibration. The drop in pressure at the flow rate measuring probe amounts – depending on the dust precipitation - approximately to 40 hPa at a flow rate of 1 m^3/h.

3. Volume flow at the sampling head or respectively at the measuring device:

Pursuant to the general gas laws it follows

$$Q_{VolKopf} = \frac{T_1}{T_0} * \frac{P_0}{P_3} * Q_{Norm}$$

where:

T1 = outside temperature

P3 = barometric pressure

When calculating the concentration value, it may be either referred to the volume flow at the sampling head or to standard volumetric flow. Both air flow rates are displayed in the menu “Air flow rate.”

Air Flow Rate Regulation

With the Model 5012 black carbon monitor, the air flow rate measured is maintained at a constant level by means of a speed-controlled pump.

CHAPTER 9
OPTIONAL EQUIPMENT

This chapter describes the Model 5012 optional equipment.

The Model 5012 MAAP comes as a standalone unit with an external vacuum pump and capable of 1 year worth of data storage.

HEATER

P/N 107991-00: 3 feet Heated Sample Tube

INLET ASSEMBLIES

The basic approach to monitoring for black carbon is to simply use a sampling cane in an attempt to capture all suspended particulate. However, an increasing customer base is interested in comparing the fraction of black carbon to a reference method of specific particle size. Therefore optional inlet assemblies are available.

The Model 5012 is extremely versatile and can be used for different applications. Using different inlet configurations (PM10, PM2.5, PM1, TSP Inlets) or enrichment techniques (PM10-2.5), several particle size fractions can be monitored. The main application is the measurement of PM10 and PM2.5 for ambient air quality and health effect studies. With additional dilution equipment and source probes, the Model 5012 can also serve as a continuous emission monitor for black carbon. By enriching the particulate sample through the means of virtual impaction, the Model 5012 can also be used as a direct measurement of PM Coarse (PM10 – PM2.5) Black Carbon.

Currently, Thermo Fisher Scientific offers inlet assemblies for PM10, PM2.5, PM1 and TSP.

10 Micron Inlet

P/N 57-000596: U.S. EPA PM10 Inlet as per 40 CFR at 16.67 l/min

2.5 Micron Inlet

P/N 57-004006: 2.5 Micron WINS Impactor
P/N 57-005896: 2.5 Micron Sharp-Cut Cyclone (SCC) at 16.67 l/min
P/N 57-008740: 2.5 Micron Very Sharp-Cut Cyclone (VSCC) at 16.67 l/min

1.0 Micron Inlet

P/N 10-67742: 1.0-Micron Sharp-Cut Cyclone at 16.67 l/min

TSP Inlet

P/N FH158: TSP Inlet at 16.67 l/min

SAMPLING TUBE EXTENSIONS

Often the compatible way to install the Model 5012 at air quality monitoring sites is to collocate the inlet at the same height as other inlets. In addition to using the above referenced inlets, extending the sample down tube length is necessary using a rigid sample tube. Extended lengths of flexible tubing can lead to particle loss.

P/N 424250222: 9.75 feet (3 m) Sampling Tube, without heater
P/N 424250214: 31-inch (800 mm) Sampling Tube, without heater
P/N 424250215: 16-inch (400 mm) Sampling Tube, without heater
P/N DDF16: Roof Mounting Flange for Sampling Tube, 16 mm diameter

WEATHER ENCLOSURE

P/N SM149248350: Protective Housing for Ambient Temperature Sensor

RACK MOUNTING ACCESSORIES

P/N 425451065: Telescope Plate
P/N KT149140871: Telescope Mount Bars, 1 pair, for 19-inch Rack Mounting

ANALOG EXTENSION

P/N 425451029: Printed Circuit Board(s) Potential-Free Separation
P/N 425451026: Analog I/O Expansion Board

Appendix A
Warranty

Seller warrants that the Products will operate or perform substantially in conformance with Seller's published specifications and be free from defects in material and workmanship, when subjected to normal, proper and intended usage by properly trained personnel, for the period of time set forth in the product documentation, published specifications or package inserts. If a period of time is not specified in Seller's product documentation, published specifications or package inserts, the warranty period shall be one (1) year from the date of shipment to Buyer for equipment and ninety (90) days for all other products (the "Warranty Period"). Seller agrees during the Warranty Period, to repair or replace, at Seller's option, defective Products so as to cause the same to operate in substantial conformance with said published specifications; provided that (a) Buyer shall promptly notify Seller in writing upon the discovery of any defect, which notice shall include the product model and serial number (if applicable) and details of the warranty claim; (b) after Seller's review, Seller will provide Buyer with service data and/or a Return Material Authorization ("RMA"), which may include biohazard decontamination procedures and other product-specific handling instructions; and (c) then, if applicable, Buyer may return the defective Products to Seller with all costs prepaid by Buyer. Replacement parts may be new or refurbished, at the election of Seller. All replaced parts shall become the property of Seller. Shipment to Buyer of repaired or replacement Products shall be made in accordance with the Delivery provisions of the Seller's Terms and Conditions of Sale. Consumables, including but not limited to lamps, fuses, batteries, bulbs and other such expendable items, are expressly excluded from the warranty under this warranty.

Notwithstanding the foregoing, Products supplied by Seller that are obtained by Seller from an original manufacturer or third party supplier are not warranted by Seller, but Seller agrees to assign to Buyer any warranty rights in such Product that Seller may have from the original manufacturer or third party supplier, to the extent such assignment is allowed by such original manufacturer or third party supplier.

In no event shall Seller have any obligation to make repairs, replacements or corrections required, in whole or in part, as the result of (i) normal wear and tear, (ii) accident, disaster or event of force majeure, (iii) misuse, fault or negligence of or by Buyer, (iv) use of the Products in a manner for which

they were not designed, (v) causes external to the Products such as, but not limited to, power failure or electrical power surges, (vi) improper storage and handling of the Products or (vii) use of the Products in combination with equipment or software not supplied by Seller. If Seller determines that Products for which Buyer has requested warranty services are not covered by the warranty hereunder, Buyer shall pay or reimburse Seller for all costs of investigating and responding to such request at Seller's then prevailing time and materials rates. If Seller provides repair services or replacement parts that are not covered by the warranty provided in this warranty, Buyer shall pay Seller therefor at Seller's then prevailing time and materials rates. ANY INSTALLATION, MAINTENANCE, REPAIR, SERVICE, RELOCATION OR ALTERATION TO OR OF, OR OTHER TAMPERING WITH, THE PRODUCTS PERFORMED BY ANY PERSON OR ENTITY OTHER THAN SELLER WITHOUT SELLER'S PRIOR WRITTEN APPROVAL, OR ANY USE OF REPLACEMENT PARTS NOT SUPPLIED BY SELLER, SHALL IMMEDIATELY VOID AND CANCEL ALL WARRANTIES WITH RESPECT TO THE AFFECTED PRODUCTS.

THE OBLIGATIONS CREATED BY THIS WARRANTY STATEMENT TO REPAIR OR REPLACE A DEFECTIVE PRODUCT SHALL BE THE SOLE REMEDY OF BUYER IN THE EVENT OF A DEFECTIVE PRODUCT. EXCEPT AS EXPRESSLY PROVIDED IN THIS WARRANTY STATEMENT, SELLER DISCLAIMS ALL OTHER WARRANTIES, WHETHER EXPRESS OR IMPLIED, ORAL OR WRITTEN, WITH RESPECT TO THE PRODUCTS, INCLUDING WITHOUT LIMITATION ALL IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. SELLER DOES NOT WARRANT THAT THE PRODUCTS ARE ERROR-FREE OR WILL ACCOMPLISH ANY PARTICULAR RESULT.

APPENDIX B

RS-232 COMMANDS

The RS-232 interface enables the Model 5012 to be remotely controlled by a host RS-232 device such as a PC, PLC, datalogger, etc.

CONNECTIONS

On the rear panel of the analyzer there are two female connectors labeled COM1 and COM2. These connectors are 25-pin and 9-pin, respectively. Either connector can be connected to the remote device. The remaining connector can be used to connect a second serial output.

REMOTE CONTROL

The transmission of all data takes place via the following settings:

- Bits per Second = 9600, 4800, 2400, 1200, 600 or 300
- Data Bits = 7
- Parity = Even
- Stop Bits = 2
- Flow Control = Hardware

As a rule, a remote command always consists of a character or special character and, if necessary, followed by numbers. A stop code forms the end of a command.

The stop code either is <CR> (carriage return) or <LF> (line feed). However, it is also permitted to send several stop codes. Besides the characters <CR> and <LF> also the character 7Fhex, or respectively FFhex can be used as stop code.

The Model 5012 is provided with a receive buffer of 256 characters. Consequently, also several commands can be received immediately one after the other. To give an example; a complete set of parameters (approx. 20 commands) can be sent to the Model 5012 as one contiguous string of commands.

A device address is a number followed by a colon. Consequently, a command usually looks like the following:

[Address][:]Command code number stop code

The information in brackets is optional.

As far as the execution of the command is concerned, it makes no difference whether a command is entered via the keyboard or via the serial interface.

In case that the system detects unreasonable parameters when receiving a command (i.e., parameters that are no longer within the admissible range) the respective command will not be executed and the error counter will increment by 1.

The Model 5012 monitor incorporates 2 serial interfaces. "COM1" is connected to a 25-pin D-sub plug connector.

The interface "COM2" is wired to a 9-pin D-sub plug connector and can be connected to the interface of a computer using a 1:1 cable. Both interfaces are equally good and can be also operated simultaneously.

The only exception: a software update is only possible using the COM1 interface.

The command codes are split into 3 groups: READ-, WRITE- and CONTROL-commands and are listed in alphabetical order. The word "number" found in a command always stands for the entry as a maximum 7-digit integer number, unsigned. Leading space characters are permitted.

Data sent by the monitoring device Model 5012 always end with <CR><LF>. The guaranteed response time to a remote control command amounts to one second.

Unless stated otherwise, numbers usually consist of 6 characters, representing a maximum 5-digit integer number, ranging from -9999 to 99999 having at least one leading space character.

REMOTE CONTROL COMMANDS

Read Commands

C	Readout of the concentration of black carbon in ng/m^3
m1	Mass of black carbon (MBC) in µg
H	Readout of the last measured value in ng/m^3
H1	Mean value of the last hour in ng/m^3, continuously updated
H3	Mean value of the last three hours in ng/m^3, continuously updated
HT	Mean value of the previous day in ng/m^3, updated at midnight
I0..I7	Readout of analog channel 1..8 in LSB
IA..ID	Readout of analog channel 9..12 in LSB
J0..JF	Readout of the sensor data in physical units
J0	Orifice pressure P_1 in hPa
J1	Pump pressure P_2 in hPa
J2	Barometric pressure P_3 in hPa
J3	Ambient temperature T_1 in °C
J4	Measuring head temperature T_2 in °C
J5	System temperature T_3 in °C
JA	Photo detector reference Sref
JB	Photo detector reflection 135° S135
JC	Photo detector reflection 165° S165
JD	Photo detector transmittance S0
JJ	Air flow rate under operating conditions
JK	Air flow rate under standard conditions
JL	Air flow rate under operating or standard conditions, according to reference selected
JM	Pump regulation signal [0..4096]
JN	Volume starting from the last measurement
N	Reading transmission error counter In case an error occurred when receiving data, such as - parity error - invalid parameter then, the error counter is incremented. The counter is reset (zero) through the reading procedure.
v	Readout device type, software version and serial number
Z	Reading date/time Response: yy-mm-tt hh:mm:ss
ZZ	Reading date/time

	Response: yymmtthhmmss
?	Reading device address / identification code
#	Readout device status. The complete status error-, warning- and operating status is output as a string comprising 19 characters. Each character represents 4 status bits, displayed hexadecimally. The first 16 characters show the detailed error status, the last 3 characters the global error-, warning/alarm and operating status.

Write Commands

K	Setting parameters	Value range
K0	Measuring interval (1, 5, 10, 30 min)	0..3
K1 [x]	Filter change, if transmittance < x %	0..99
K2 [x]	Filter change every XXX hours	1..100
K3 [x]	Filter change at XXX hours 0: no filter change at fixed point in time	0..24
K4 [x]	Air flow rate, nominal value X l/h	0..3000
K5 [x]	Zero point of the analog output (0 = 0 mA, 1 = 4 mA)	
K6 [x]	Analog output CBC: Min.	0..1000
K7 [x]	Analog output CBC: Max.	0..9999
K8 [x]	Quantity to be measured at the analog channel 2	0..9
K9 [x]	Analog output channel 2: Min.	0..1000
KA [x]	Analog output channel 2: Max.	0..9999
KB [x]	Analog output Q_{OP}: Min. value of the volume flow	0..1000
KC [x]	Analog output Q_{OP}: Max. value of the volume flow	0..9999
KD [x]	Analog output T_1: Min. value of the air temperature	0..100
KE [x]	Analog output T_1: Max. value of the air temperature	0..100
KF [x]	Analog output T_2: Min. value of meas. head temperature	0..100
KG [x]	Analog output T_2: Max. value of the head temperature	0..100
KH [x]	Quantity to be measured at the analog channel 6	0..9
KI [x]	Analog output channel 6: Min.	0..1000
KJ [x]	Analog output channel 6: Max.	0..9999
KK [x]	Language flag (0: German, 1: English)	
KL [x]	Air flow rate calibration factor	0..100
KM [x]	Concentration reference (0: operating, 1: standard conditions)	
KN [x]	Standard temperature	0..100
GN	Number of variables in the Gesytec-protocol string	1..7
GS	Status version (0: I-N compatible, 1: standard)	
G [x] [y]	Number x variable in the protocol, y: qty. to be measured	
D [x]	Setting the print format of the active interface (COM1/2)	
d1 [x]	Setting print format of COM1	

d2[x]	Setting print cycle to x minutes	
d3[x]	Setting print cycle to x seconds	
d4[x]	Setting baud rate for both COM interfaces	0..6
d8[x]	Setting print format of COM2	
dA[nnn]	Setting 3-digit serial number **nnn**	

Y	Loading parameters from the EEPROM
Y$	Writing parameters to the EEPROM
Z[yymmtthhmmss]	Setting the clock

Control Commands

o1	Setting the monitoring instrument ONLINE
o0	Setting the monitoring instrument OFFLINE

A	Switching off the pump
E	Switching on the pump

L0	LED off
L1	LED on

F	Releasing a filter change

MON Setting the monitor mode.
After having entered this command, all characters received are shown on the display. This mode may be very useful for testing the connecting cables and the transmission software installed on the computer.
On top of that, this mode makes it possible to write messages on the display.

<ESC> To quit the monitor mode, please use this command.
Received characters then will be no longer represented, but again interpreted as command. The display returns to the mode where the concentration values are shown.

P	A printout is initiated according to the print format set
R	Reset This command has the same effect as switching the supply voltage ON and OFF

Output control for file output

/S	Stop
/C	Continue
/T	Terminate

b [yy mm tt hh]
Setting the date for terminating the file output.
Data from the files are output starting from current date until the date set.

DATA PROTOCOLS WITH MEASURING NETWORK CONNECTION

Once the character <STX> (usually: Ctrl-B) has been received, the monitoring instrument Model 5012 starts processing the data received at the serial line according to the protocol that has been agreed upon for devices operating in a measuring network.

To prevent the measuring instrument from executing data outputs on its own, we strongly recommend setting the print format to 0.

This is the basic structure of a data protocol:

<STX>[Text]<ETX><BCC1><BCC2>

Instead of <ETX><BCC1><BCC2> it is also possible to send <CR>. In doing so, the block check will be disabled.

The response of the measuring device will be terminated by <CR><LF>, if the control or inquiry command had an <CR> at the end. If the command is terminated with <ETX> (usually: Ctrl-C) and block check, the response of the measuring instrument will be also terminated with <ETX> and <BCC1><BCC2>.

Data Sampling

Upon request, the measuring instrument sends a measuring data protocol. Transmission of the measuring data is released by the following sequence of characters:

<STX>DA[Address]<ETX><BCC1><BCC>

where Address: Device address, 3 characters, leading zeros can be replaced by <SP>. It is also possible that the address can be completely dropped. The address at the measuring instrument is set by using the keyboard (Menu OPERATION: Device address).

Sampling is valid and response will be given, if

- the <STX> is followed by the characters DA,
- the address is correct or not existing,
- the <ETX> is followed by two correct BCC-characters
- or <ETX><BCC1><BCC2> is replaced by <CR>.

The following is an example for a valid inquiry at the device having the address 5:

```
<STX>DA<CR>
<STX>DA005<CR>
<STX>DA<SP><SP>5<ETX><BCC1><BCC2>
<STX>DA<ETX>04
```

Data Transmission

The data inquiry may comprise up to seven variables. As a consequence, the response then contains the respective number of blocks, each block beginning with the address and ending with [SFKT]. With each block, the address will be incremented by 1.

The transmission of measured data is effected as response to the data inquiry/data sampling (1). The format will be as follows (here in this case with 2 variables):

```
<STX>MD0[n]<SP>

[Address]<SP>[Measured value 1]<SP>[Status]<SP>[Serial
no.]<SP>[SFKT]<SP>

[Address+1]<SP>[Measured value 2]<SP>[Status]<SP>[Serial
no.]<SP>[SFKT]<SP>

<ETX><BCC1><BCC2>
```

[n]:	Number of variables
[Address]:	Device address set, 3 characters, leading zeros are transmitted
<SP>:	Space character
[Measured value]:	Indicated in $\mu g/m^3$, exponential representation with 4 characters mantissa and 2 characters exponent, each one with sign. Mantissa: sign followed by 4 numerical characters. The decimal point is located after the first two decimal characters and is not transmitted. Exponent: sign followed by 2 numerical characters, leading zeros are included in the transmission. Micro or nano??
[Status]:	4 characters, operational and error status byte, each one being represented by two characters, formed like the BCC: operating status <SP> error status
[Serial no.]:	Number of manufacture to guarantee unique device identification
[SFKT]:	Special function, not used, six times the numerical character 0.

Significance of the operating status bits:

1) Operating and error status
2) Compatible with FH 62 I-N
   D1 : Keyboard active
   D2 : Filter change

Significance of the error status bits:

D0 : Air flow disturbed
D1 : Breach or end of the filter tape
D2 :
D3 : Sampling buffer not filled

<ETX>[BCC1][BCC2] is replaced by <CR><LF>, if the data inquiry has been terminated by <CR>.

Example: GEI (Bavaria/Hessia) protocol including the transmission of the number of black carbon and the concentration of black carbon:
Inquiry: <STX>DA<CR>
Response: <STX>MD03 001 +2578+03 00 00 023 000000<SP>
↑ Address ↑ CBC ↑ Serial number

```
002 +5681+00 00 00 023 000000<SP>
003 +1001+03 00 00 023 000000<CR>
```

Remote Control

The measuring instrument is controlled by the following protocol:

<STX>ST[Address]<SP>[Command]<ETX>[BCC1][BCC2]

Address: Device address, 3 characters, leading zeros may be replaced by <SP>.

The address may be also dropped. In this case, the first command character directly must follow the characters ST.

Command: All commands listed are admissible commands to be applied.
The response coming from the device, however, is sent without protocol.
For this reason, no read commands should be used.

In case that the control command is accepted by the measuring instrument (the characters ST follow the <STX>, correct address, correct block check), then the command will be executed.

It is allowed to replace <ETX>[BCC1][BCC2] by <CR>.

How to form the block check character (BCC1, BCC2):

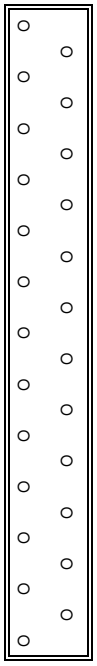
The BCCs are formed by simply building the exclusive OR operation byte-by-byte over all characters transmitted (incl. <STX>, <ETX>) (based on 00hex). The bit that results is sent as hexadecimal number with two ASCII characters.

Example: BCC binary: 01011010
Is transmitted by the ASCII characters: 5A

APPENDIX C

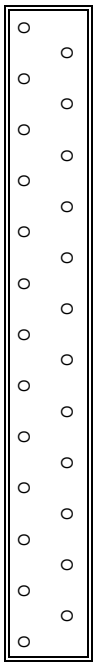
CONNECTOR AND BOARD SCHEMATICS

Female connector COM1



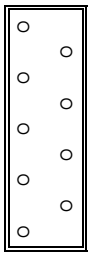
1	Shielding
14	
2	TD
15	
3	RD
16	
4	RTS
17	
5	CTS
18	
6	
19	
7	GND
20	
8	
21	
9	
22	
10	
23	
11	
24	
12	
25	
13	

Female connector standard I/O



1	Relay 0 Make contact
14	Relay 0 Break contact
2	Relay 0 Center contact
15	Relay 1 Make contact
3	Relay 1 Break contact
16	Relay 1 Center contact
4	Relay 2 Make contact
17	Relay 2 Break contact
5	Relay 2 Center contact
18	
6	
19	
7	
20	
8	
21	
9	Input
22	GND for Input
10	
23	
11	
24	+20 mA Mass
12	+20 mA Concentration
25	-20 mA Mass
13	-20 mA Concentration

Female connector COM2



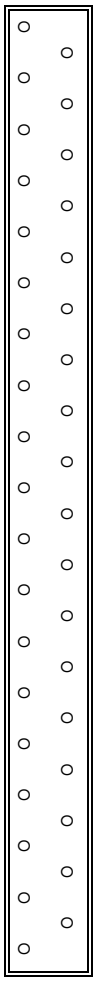
1	
6	-12V
2	TD
7	CTS
3	RD
8	-12V
4	
9	
5	GND

Relay 0: Operating status
Relay 1: Limit value
Relay 2: Failure
Loading capacity of the contacts:
max 60V/ 0.5A
Rest: Relay picked-up

Analog outputs 0..10V:
Internal resistance : $< 1\ \Omega$
Maximum output current: 5 mA

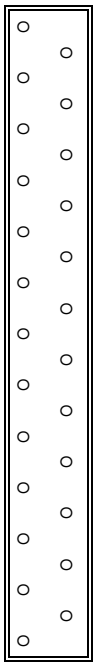
Analog outputs 0..20mA:
Maximum load: $500\ \Omega$

Female connector standard I/O extension



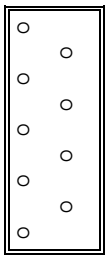
1	Relay 0 Make contact
20	Relay 0 Break contact
2	Relay 0 Center contact
21	Relay 1 Make contact
3	Relay 1 Break contact
22	Relay 1 Center contact
4	Relay 2 Make contact
23	Relay 2 Break contact
5	Relay 2 Center contact
24	Relay 3 Make contact
6	Relay 3 Break contact
25	Relay 3 Center contact
7	Relay 4 Make contact
26	Relay 4 Break contact
8	Relay 4 Center contact
27	Relay 5 Make contact
9	Relay 5 Break contact
28	Relay 5 Center contact
10	
29	+IN 1
11	-IN 1
30	GND
12	+IN 2
31	-IN 2
13	GND
32	+IN 3
14	-IN 3
33	GND
15	+IN 4
34	-IN 4
16	GND
35	
17	
36	+20mA Mass
18	+20mA Concentration
37	-20mA Mass
19	-20mA Concentration

Female connector analog I/O



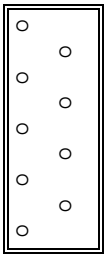
1	+15V
14	AIN1
2	-15V
15	EEPROM DO
3	AIN5
16	AIN6
4	AIN7
17	AIN8
5	EEPROM CS
18	GND
6	AIN2
19	GND
7	0..10V OUT C
20	AIN 3
8	SHIFT CLOCK (SK)
21	0..10V OUT A
9	AIN4
22	SER. OUT (DI)
10	0..10V OUT B
23	TRIM DAC LD
11	GND
24	0..10V OUT D
12	GND
25	
13	GND

Female connector 4..20 mA



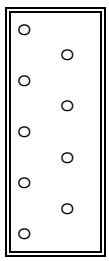
1	+20mA A (Air flow rate)
6	-20mA A (Air flow rate)
2	+20mA B (Temp. PM10-head)
7	-20mA B (Temp. PM10-head)
3	+20mA C (Channel 5)
8	-20mA C (Channel 5)
4	+20mA D (Channel 6)
9	-20mA D (Channel 6)
5	

Female connector PUMP



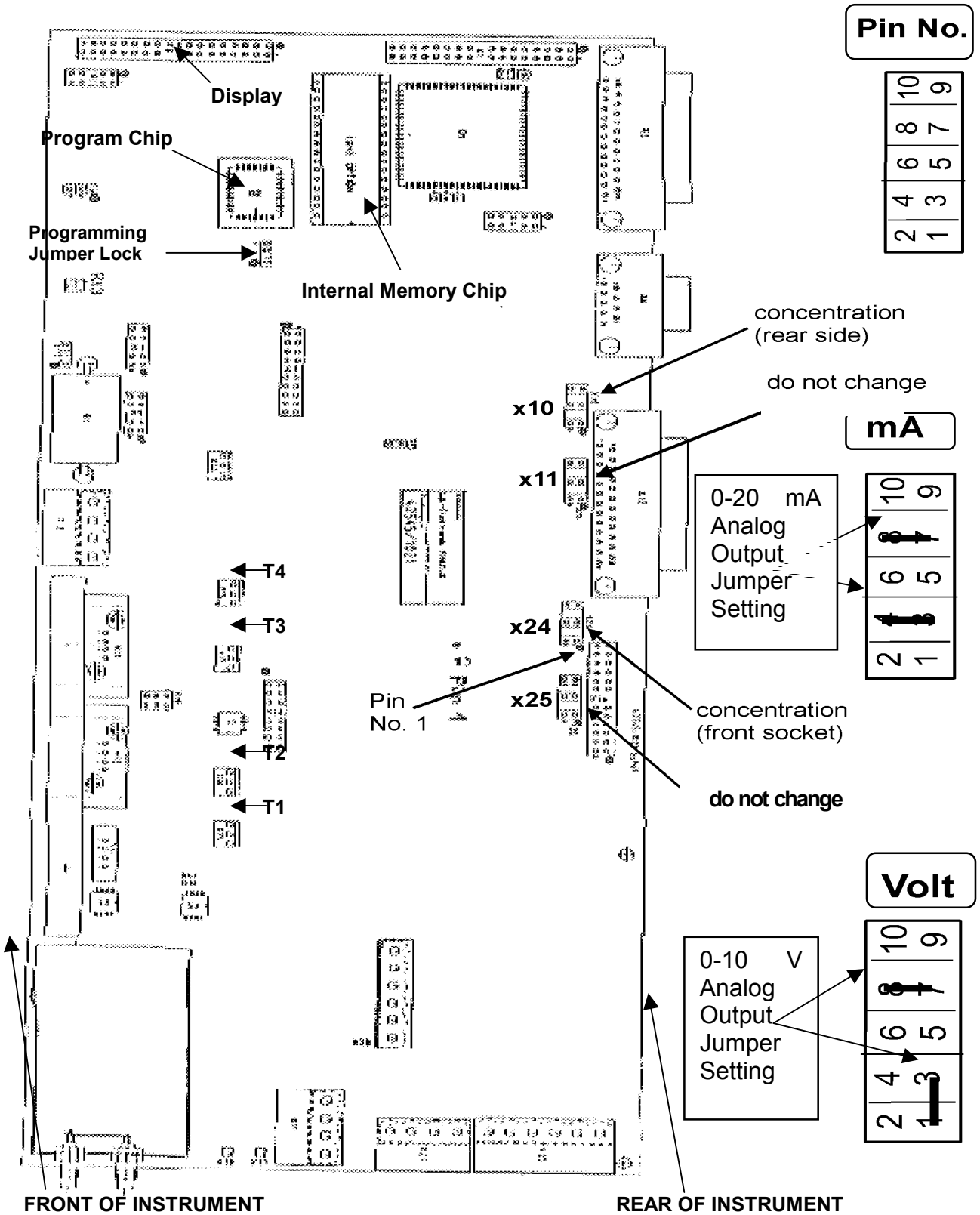
1	GND
6	+0..10V, Pump regulation
2	
7	
3	
8	
4	
9	
5	

Female connector SENSORS



1	
6	
2	
7	
3	
8	Sensor T1, Ambient temp.
4	Sensor T1, Ambient temp.
9	Sensor T4
5	Sensor T4

Model 5012 Main Circuit Board



APPENDIX D

AEROSOL ARTICLE

Aerosols

Continuous Measurement of Atmospheric Black Carbon Using a Multi-angle Absorption Photometer

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Absract. A new instrument is presented which is conducting the measurement of the atmospheric black carbon loading by the application of a radiative transfer scheme to particle-loaded fiber filters. This method includes multiple-scattering effects into the analysis of the aerosol-filter system and is therefore aiming on a reduction of the uncertainties of the measured aerosol absorption coefficient and the black carbon mass loading of the filter sample. A detailed analysis of the filter scattering phase function was used to develop a simplified optical sensor which is capable to simultaneously measure radiation fields in the forward and backward hemisphere with respect to the aerosol-filter system. First calibration studies using ambient aerosol samples show a robust determination of black carbon mass loading. The obtained absorbance coefficient σ_{ABS} (λ = 0.67 µm) = 6.5 ± 0.5 m^2 g^{-1} for the black carbon particles is close to values reported for diesel particles (5–8 m^2 g^{-1}). Results of a side-by-side operation of two instruments show an excellent agreement (r^2 = 0.964) with an average ratio between both instruments of 0.99 ± 0.12.

Keywords: Aerosol absorption coefficient; aerosol light absorption; air quality monitoring; air pollution; atmospheric aerosols; black carbon

1 Background

The atmospheric black carbon load is still a matter of concern, in particular regarding air quality aspects and related adverse health effects. Nevertheless, the problem of measuring black carbon by simple and robust but precise techniques especially in air quality monitoring networks remains unsolved yet. The German thermal reference method for the determination of atmospheric black carbon (VDI 1996, Petzold and Niessner 1995) is based on solvent extraction and thermal desorption of glass fiber filters to remove the organic carbon, followed by combustion of the remaining black carbon. This method gives 24 h average mass concentration values which is sufficient to control an annual mean limiting value, but on the other hand the method is time consuming and expensive. Hence, there is urgent need for optically based continuously working instruments which can be employed for an automated black carbon monitoring.

The most common instrument used currently for these purposes is the Aethalometer (Hansen et al. 1984) which is based on the optical analysis of particle-loaded quartz fiber filters. The Aethalometer is measuring the change in filter transmission caused by the deposited aerosol particles. This particle-related attenuation *ATN* of transmitted light is related to the black carbon mass loading of the filter S_{BC} via (Gundel et al. 1984)

$$ATN = -100 \ln \frac{T}{T_0} = \sigma_{ATN} S_{BC} \quad (1)$$

where T and T_0 denote intensities of transmitted light with respect to the particle loaded and the blank filter, σ_{ATN} is a proportionality factor which links the attenuation to the black carbon mass loading, unit is m^2 g^{-1}. The factor 100 balances the units of S_{BC} (µg cm^{-2}) and σ_{ATN} (m^2 g^{-1}). To convert attenuation data into black carbon mass loading, a precise knowledge of the attenuation coefficient σ_{ATN} is of great importance.

It was shown by several authors that the assumption of a constant σ_{ATN} value as it is recommended by the manufacturer, is not justified. The reported values range from 5 m^2 g^{-1} to >20 m^2 g^{-1}, depending on the type of sampled aerosol (Liousse et al. 1993, Petzold et al. 1997, Hansen et al. 2001). An analysis of attenuation measurements and independent measurements of atmospheric black carbon via a thermal method (Petzold et al. 1997) showed that the σ_{ATN} value is affected by the fraction of exclusively light-scattering components of the aerosol. This conclusion was recently confirmed by a study (Bond et al. 1999) on the Particle Soot Absorption Photometer (PSAP; Radiance Research Inc. Seattle, USA) which works similar to the Aethalometer. The authors demonstrated for the PSAP that the interpretation of attenuation data has to consider also light-scattering effects which is in accordance with the observations by Petzold et al. (1997). A theoretical investigation of the applicability of the relationship Eq. (1) based on the Kubelka Munk theory which takes multiple scattering effects explicitly into account yielded that the Aethalometer approach is valid only for thin aerosol layers on a filter matrix with a high black carbon mass fraction (>10%) and a low scattering coefficient (Lindberg et al. 1999). These conditions are usually met at urban measurements sites. At rural and remote sites the Aethalometer approach is expected to overestimate the black carbon loading.

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Besides the above-described attenuation measurement, also a set up measuring the change in filter reflectance is in use (Bailey and Clayton 1982). The relationship between filter reflectance *REF* and filter black carbon mass loading S_{BC} is

$$REF = -100 \ln \frac{R}{R_0} = 2\,\sigma_{REF}\; S_{BC}\,. \qquad (2)$$

Similar to Eq. (1) R and R_0 denote the reflectance of a particle-loaded and a clean filter, the coefficient σ_{REF} is again given as a mass specific cross section. A study on the dependence of σ_{REF} on aerosol composition and size (Kopp et al. 1999) yielded that the reflectance coefficient is not that strongly influenced by the light-scattering aerosol fraction than the attenuation coefficient, but there was still a considerable dependence observed. It was also demonstrated in this study that the coefficients σ_{ATN} and σ_{REF} are different for the same aerosol because the interactions between aerosol layer and filter matrix are different for both techniques. Additionally, the values for σ_{ATN} and σ_{REF} differ from the specific absorption cross section σ_{abs} for airborne black carbon particles because airborne particles do not face any multiple scattering processes caused by a surrounding filter matrix. This deviation from the 'true' value σ_{abs} can reach up to an order of 30% for an aerosol deposited on a plane membrane filter (Hitzenberger et al. 1993), while in the case of a fiber filter matrix it may become a factor of 2 and more for the Aethalometer.

Therefore, a method is required which is capable of measuring the aerosol black carbon content almost free of artifacts caused by the aerosol-light-scattering fraction. A possible approach could be the application of a radiative transfer scheme during the analysis of the filter optical properties which takes multiple-scattering effects explicitly into account. In the following the development and application of an instrument will be presented which combines the simplicity of a filter-tape instrument for long-term continuous black carbon monitoring and the analysis of the filter optical properties employing a radiative transfer technique which was originally developed for the analysis of single filter samples (Hänel 1987).

2 Instrument Development

2.1 Sensor Set Up

The application of a radiative transfer scheme to the analysis of a particle-loaded filter requires knowledge on the radiation field in the forward and back hemisphere of the aerosol-filter system. Since the presented efforts were aiming at a simple instrument for continuous black carbon monitoring a new optical sensor had to be developed which is capable of simultaneously measuring both radiation fields. For this purpose, the scattering phase function of blank and particle loaded filters were first investigated using a polar photometer set up shown in **Fig. 1**. Using this polar photometer, filter samples were investigated which were loaded with a mixture of black carbon (BC) and NaCl aerosols or pure BC. The generation of these aerosols is described with more detail elsewhere (Kopp et al. 1999).

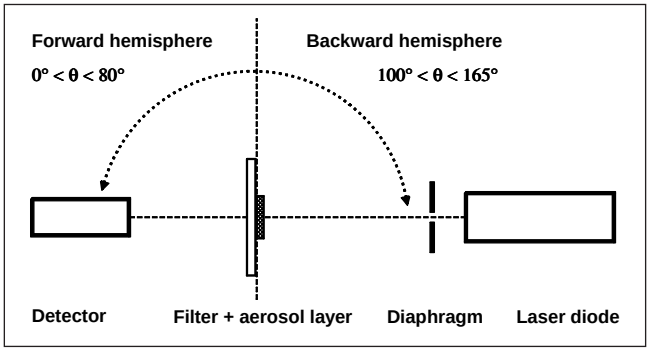

Fig. 1: Schematic set-up of the polar photometer to measure the angular distribution of radiation scattered by an aerosol-loaded fiber filter

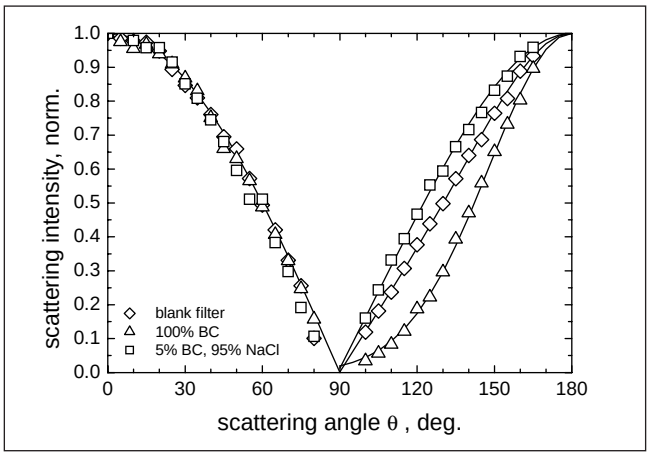

Fig. 2: Filter scattering phase functions for a blank filter, a strongly absorbing aerosol (100% black carbon) and a highly scattering aerosol (95% NaCl)

Fig.2 shows the angular distribution of radiation for a blank filter, pure BC aerosol and an aerosol with a very low absorbing fraction. Obviously, the angular distribution of the radiation passing through the aerosol-filter system into the forward hemisphere does not depend on the aerosol composition, but follows a simple cosine law

$$S(\theta) \propto \cos\theta \qquad (3)$$

Therefore, a single detector placed at θ = 0° is sufficient to cover the angular distribution of the radiation completely.

On the other hand, the angular distribution of the radiation scattered into the back hemisphere shows a clear effect of the aerosol composition. The absorbing aerosol is reducing the amount of light scattered sideward, while the highly scattering aerosol is increasing this fraction with respect to the blank filter matrix. The filter phase function in the back hemisphere can be best described by a combination of diffuse scattering following the cosine law Eq. (3) and a specular component described by a Gaussian distribution with its width (ρ = 0.5) being a measure for the surface roughness of the filter. The resulting phase function is

$$S(\theta) \propto \left(\alpha \cos\theta + (1-\alpha) \exp\left[-\frac{1}{2} \frac{\theta^2}{\rho^2} \right] \right) \qquad (4)$$

where α denotes the diffuse fraction of the scattered radiation.

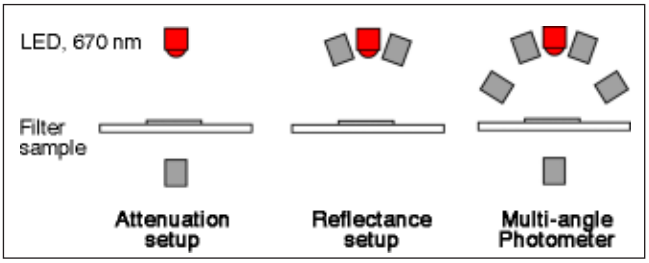

Fig. 3: Schematic set up for attenuation and reflectivity measurements compared to the multi-angle photometer set up

Fig. 2 also indicates that the difference between the phase functions is largest for scattering angles $\theta \cong 130°$, while a sensor positioned at $\theta = 165°$ is monitoring the backscattered radiation. Hence, placing a second detector at $\theta \cong 130°$, a simple and robust optical set up is achieved which can cover the angular distribution of radiation in the back hemisphere. Analyzing the dependence of the signal measured under a certain scattering angle from the filter scattering phase function, a strong linear relationship ($r^2 = 0.99$) between the diffuse fraction α and the ratio of signals $S(\theta \cong 130°) / S(\theta = 165°)$ is found. This linear relationship is used to calculate α from the measured signal ratio $S(\theta \cong 130°) / S(\theta = 165°)$. More details on the evaluation of the optimum sensor position and the determination of the diffuse fraction α from the measured signals are given in a separate paper (Petzold 2002). Finally, **Fig. 3** summarizes schematically the current optical set ups for attenuation and reflectivity measurements and compares them with the developed multi-angle photometer.

2.2 Data Inversion

The determination of the aerosol absorption coefficient and the black carbon loading of the filter sample under investigation uses radiative transfer techniques. The applied approach was developed by Hänel (1987) and modified for the presented work (Petzold 2002). Because details can be found in these two references, the method will only briefly be summarized here.

The discussion of radiative processes which are relevant in a system being composed of an aerosol being deposited on a filter matrix has to consider the layer optical properties T (fraction of transmitted radiation), F (fraction of forward scattered radiation), B (fraction of back scattered radiation), and P (fraction of radiation passed through the particle-loaded filter) with $P = T + F$. Subscripts M, L, and F denote the properties of the blank filter matrix, the aerosol-loaded filter layer, and the composite system, respectively; superscript * indicates the value for diffuse incident radiation while no superscript indicates values for collimated incident radiation.

The consideration of multiple scattering effects between the particle-loaded filter layer and the particle-free filter matrix, and scattering processes inside the aerosol layer yields the following equations for the ratio of radiation passed through a particle-loaded and a blank filter, *trans*, and for the ratio of radiation scattered from a particle-loaded and a blank filter, *ref*, (Petzold 2002).

$$trans = \frac{P_F}{P_F^{(0)}} = \frac{T_L + F_L}{1 - B_L^* B_M} \qquad (5)$$

$$ref = \frac{B_F}{B_F^{(0)}} = P_L^* \frac{T_L + F_L}{1 - B_L^* B_M} + \frac{B_L}{B_M} \qquad (6)$$

The filter properties $trans = P_F / P_F^{(0)}$ and $ref = B_F / B_F^{(0)}$ correspond to the ratios of measured radiation passages and reflectances for particle-loaded (P_F, B_F) and respective particle-free ($P_F^{(0)}$, $B_F^{(0)}$) filter samples. The term $(1 - B_L^* B_M)$ describes the amplification of the radiation field caused by multiple reflections between the regarded layers while $T_L + F_L$ corresponds to the radiation passing through the aerosol layer. The quantities *trans* and *ref* are directly measurable while the aerosol layer properties F_L, B_L, P_L^*, and B_L^* are calculated via radiative transfer methods (Hänel 1987, Petzold 2002). The filter matrix reflectivity was determined independently for the employed filter material as $B_M = 0.70$.

If all multiple scattering processes are neglected, i.e., $F_L = 0$, $B_L = 0$, and $B_L^* = 0$, Eqs. ,(5) and (6) transform into the relationships Eqs. (1) and (2). The presented approach contains therefore the current approaches for measuring black carbon from particle-loaded filters as an approximation.

The coupled equations (5) and (6) are solved by calculating the required properties F_L, B_L, P_L^*, and B_L^* via the variation of the two independent variables (Petzold 2002). Free parameters are the optical depth $\tau_L = -\ln T_L$ and the single-scattering albedo ω_0 of the aerosol-filter layer. According to the Lambert-Beer law, $\tau_L = \sigma S_{BC}$ or $T_L = \exp(-\sigma S_{BC})$, respectively.

From the final values τ_L and ω_0 the absorbance *ABS* of the aerosol-filter system can be derived as

$$ABS = 100\left(1 - \omega_0\right) \tau_L = \sigma_{ABS} S_{BC} \qquad (7)$$

Eq. (7) is similar to the relationships (1) and (2), but does include the consideration of multiple scattering effects via the parameters τ_L and ω_0. The calculation of the specific black carbon mass loading S_{BC} from the measured quantities *ref*, *trans*, and α is implemented as data inversion algorithm and forms the backbone of the instrument. The black carbon mass concentration c_{BC} is calculated from S_{BC}, the respective sample volume V and filter spot area A straightforward according to $c_{BC} = S_{BC} A / V$.

3 Instrument Application

The response of the method to an aerosol of varying black carbon mass fraction was first tested using a laboratory-generated mixture of black carbon and NaCl particles. The total mass of the deposited aerosol was measured gravimetrically while the black carbon mass was determined by the German reference method VDI 2465, part 1. The black carbon mass fraction of the deposited aerosol varied between 2 and 100%. As can be seen in **Fig. 4**, the response of the instrument to the light-absorbing aerosol is scarcely influenced by the light-scattering aerosol fraction.

The instrument is designed as a filter tape instrument which is capable of measuring the black carbon concentration continuously. However, for calibration purposes the measured values have to be compared to 24h average values measured with the German reference method VDI 2465, part 1. Two examples are shown in **Figs. 5** and **Fig. 6**. The instrument was first ap-

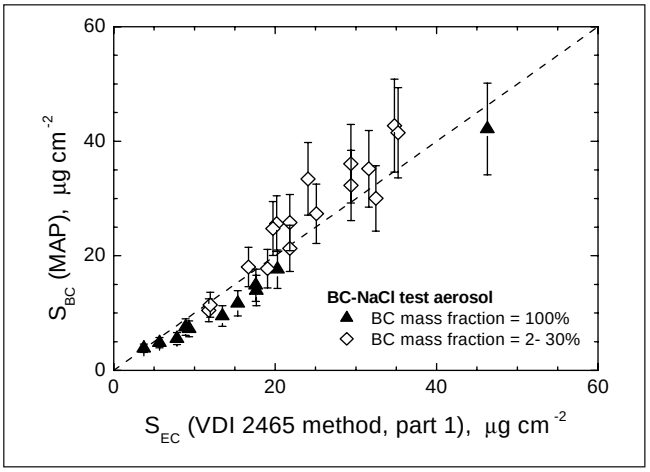

Fig. 4: Filter black carbon loading S_{BC} obtained from the multi-angle absorption photometer compared to elemental carbon loading S_{EC} determined by the German thermal reference method VDI 2465, part 1; correlation coefficient $r^2 = 0.91$ (n = 28). Error bars correspond to the uncertainty of the absorbance coefficient σ_{ABS}

plied under real conditions in October 2000 on the Mt. Kleiner Feldberg near Frankfurt, Germany, see Fig. 5. This site represented continental background conditions characterized by an average black carbon mass loading of about 500 ng m^{-3} and a black carbon mass fraction of PM_{10} fine dust of about 6%. The agreement between compared methods is remarkable, although it has to be mentioned that the reference method is operating at its limit of detection which is taken into account by the large uncertainty range. The second measurement site representing urban conditions was situated at a street intersection in Bad Krozingen, Germany, where the instrument was exposed to heavy traffic emissions, see Fig. 6. The average black carbon mass fraction of PM_{10} fine dust at this site was about 20% which is in good agreement with other observations at urban sites in Germany (Petzold and Niessner 1995). Again, the agreement between the multi-angle absorption photometer and the thermal reference method is very good.

For both measurement sites the best agreement between optical and thermal BC data is achieved when an absorbance coefficient $\sigma_{ABS} = 6.5$ m^2 g^{-1} is applied in Eq. (7). This σ_{ABS} value lies within the range of specific absorption cross sections of 5–

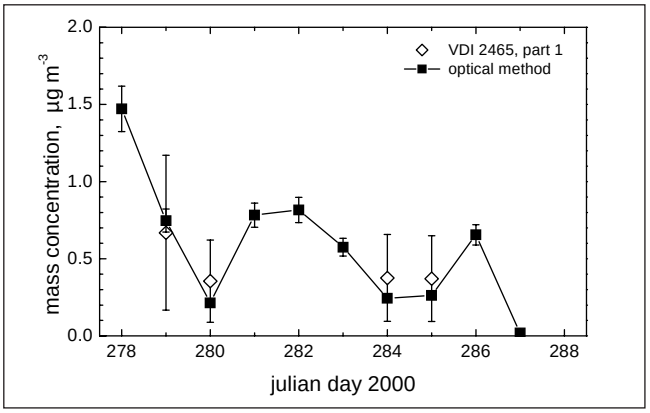

Fig. 5: Black carbon mass concentration obtained from the reference method VDI 2465, part 1, and from the multi-angle photometer; the data correspond to 24h average values measured at Mt. Kleiner Feldberg

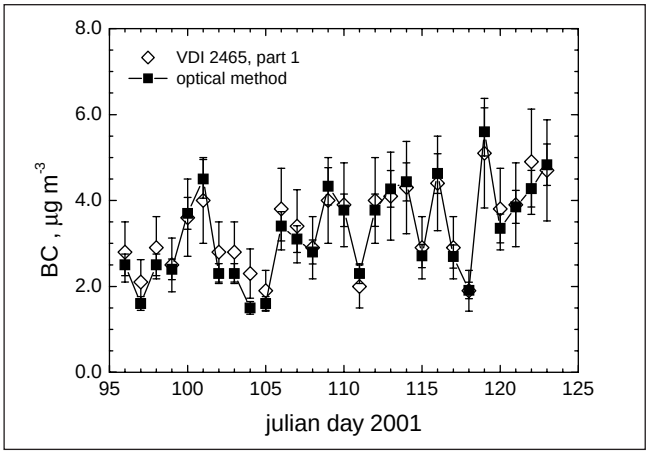

Fig. 6: Black carbon mass concentration obtained from the reference method VDI 2465, part1, and from the multi-angle photometer; the data correspond to 24h average values measured at a street intersection in Bad Krozingen

8 m^2 g^{-1} reported for airborne diesel particles (Horvath 1993). Linear regression analysis of the combined data set yielded a correlation coefficient $r^2 = 0.965$ and an average ratio BC(optical) / BC(thermal) = 0.95 ± 0.04. Concluding, the applicability of the new instrument for the measurement of atmospheric black carbon was successfully demonstrated for clean and polluted conditions spanning a range of 24h average BC concentration values from <500 ng m^{-3} to 5 µg m^{-3}.

An estimate of the detection limit of the monitoring instrument was obtained from filter blank value fluctuations. Operating the instrument with particle-free air at a standard volume flow rate of 1 m^3 h^{-1} upper detection limits of 20 and 50 ng m^{-3} were calculated for a time base of 30 min or 10 min, respectively.

Besides the calibration of the instrument against atmospheric aerosol samples as described above, the precision of the method was investigated during a side-by-side operation of two instruments. These measurements were conducted at the Thermo ESM Andersen premises at the outskirts of Erlangen, Germany, representing urban background conditions. The results shown in **Fig. 7** indicate the excellent agreement between the two instruments; correlation analysis yielded $r^2 = 0.964$ and an average ratio between the two instruments of 0.99.

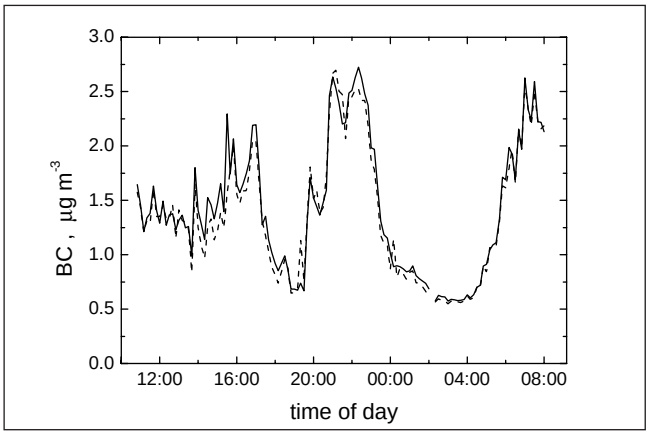

Fig. 7: Side-by-side operation of two instruments at the Thermo ESM Andersen premises in Erlangen in Fall 2001

4 Summary

A new optical instrument was developed to measure the aerosol-related absorption of light and the corresponding atmospheric black carbon mass concentration. The multi-angle absorption photometer is analyzing the modification of the radiation fields in the forward and back hemisphere of a fiber filter caused by deposited particles. The data inversion algorithm is based on radiation transfer methods and therefore takes multiple scattering processes inside the deposited aerosol and between the aerosol layer and the filter matrix explicitly into account. The disregard of these multiple scattering processes is assumed to be a major source of uncertainty in current black carbon measurement methods. The successful application of the new instrument under clean and polluted conditions is demonstrated. The intercomparison between optically obtained black carbon values and those determined by a thermal reference method indicates the applicability of a single absorbance coefficient to data sets from various measurement sites as expected from the underlying physical processes. Therefore, the interference with light scattering aerosol components seems to be small. The instrument is capable of measuring black carbon mass concentration values <20 ng m^{-3} on a 24h average basis. Under polluted conditions the sampling time is actually set to 10 min in correspondence with a sample flow of 1 m^3 h^{-1} but can be further reduced. The commercial availability of this instrument is expected in the near future, more information is given at http://www.esm-andersen.de.

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